

# ON SPECTRUM OF $\kappa$ -RESPLENDENT MODELS

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ABSTRACT. We prove that some natural “outside” property is equivalent (for a first order class) to being stable.

For a model, being resplendent is a strengthening of being  $\kappa$ -saturated. Restricting ourselves to the case  $\kappa > |T|$  for transparency, a model  $M$  is  $\kappa$ -resplendent means:

when we expand  $M$  by  $< \kappa$  individual constants  $\langle c_i : i < \alpha \rangle$ , if  $(M, c_i)_{i < \alpha}$  has an elementary extension expandable to be a model of  $T'$  where  $\text{Th}((M, c_i)_{i < \alpha}) \subseteq T', |T'| < \kappa$  then already  $(M, c_i)_{i < \alpha}$  can be expanded to a model of  $T'$ .

Trivially any saturated model of cardinality  $\lambda$  is  $\lambda$ -resplendent. We ask: how may  $\kappa$ -resplendent models of a (first order complete) theory  $T$  of cardinality  $\lambda$  are there? Naturally we restrict ourselves to cardinals  $\lambda = \lambda^\kappa + 2^{|T|}$ . Then we get a complete and satisfying answer: this depend just on  $T$  being stable or unstable. In this case proving that for stable  $T$  we get few, is not hard; in fact every resplendent model of  $T$  is saturated hence determined by its cardinality up to isomorphism. The inverse is more problematic because naturally we have to use Skolem functions with any  $\alpha < \kappa$  places. Normally we use relevant partition theorems (Ramsey theorem or Erdős-Rado theorem), but in our case the relevant partitions theorems fails so we have to be careful.

## 0. INTRODUCTION

Our main conclusion speaks on stability of first order theories, but the major (and the interesting) part of the proof has little to do with it and can be read without knowledge of classification theory (only the short proof of 1.8 uses it), except the meaning of  $\kappa < \kappa(T)$  which we can take as the property we use, see inside 2.1(1) here (or see [Sh:E59, 1.5(2)] or [Sh:c]). The point is to construct a model in which for some infinite sequences of elements we have appropriate automorphism, so we need to use “Skolem” functions with infinitely many places. Now having functions with infinite arity make obtaining models generated by indiscernibles harder. More specifically, the theory of the Skolemizing functions witnessing resplendence for  $(M, \bar{b})$  is not continuous in  $\text{Th}(M, \bar{b})$ . So we use a weaker version of indiscernibility hence though having a linear order is usually a very strong requirement (see [Sh:E59, §3]), in our proof we use it as if we only have trees (with  $\kappa$  levels).

In [Sh:a] or [Sh:c, VI 5.3–5.6] we characterized first order  $T$  and cardinals  $\lambda$  such that for some first order complete  $T_1$ ,  $T \subseteq T_1$ ,  $|T_1| = \lambda$  and any  $\tau(T)$ -reduct of a model of  $T_1$  is saturated.

In [Sh:225] we find the spectrum of strongly  $\aleph_\epsilon$ -saturated models, but have nothing comparable for strongly  $\aleph_1$ -saturated ones (on better computation of the numbers see [Sh:225a], and more in [Sh:331, 3.2]). Our interest was:

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Publication 363. This was supposed to be Ch V to the book “Non-structure” and probably will be if it materialize.

- (A): an instance of complete classification for an “outside” question: the question here is the function giving the number of  $\kappa$ -resplendent models of a (first order complete) theory  $T$  as a function of the cardinality, we concentrate on the case  $\lambda = \lambda^\kappa + 2^{|T|}$
- (B): an “external” definition of stability which happens to be the dividing line.

Baldwin had told me he was writing a paper on resplendent models: for  $\aleph_0$ -stable one there are few ( $\leq 2^{\aleph_0}$ ) such models in any cardinality; and for  $T$  not superstable — there are  $2^\lambda$  models of cardinality  $\lambda$  (up to isomorphism).

Note that resplendent models are strongly  $\aleph_0$ -homogeneous and really the non-structure are related. The reader may thank Rami Grossberg for urging me to add more explanation to 1.9.

## 1. RESPLENDENCY

Our aim is to prove 1.2 below (“ $\kappa$ -resplendent” is defined in 1.4).

**Convention 1.1.**  $T$  is a fixed first order complete theory; recall that  $\tau(T) = \tau_T$ ,  $\tau(M) = \tau_M$  is the vocabulary of  $T$ ,  $M$  respectively and  $\mathbb{L}$  is first order logic, so  $\mathbb{L}_\tau \equiv \mathbb{L}(\tau)$  is the first order language with vocabulary  $\tau$ .

We show here

**Theorem 1.2.** *The following are equivalent (see Definition 1.4 below) for a regular uncountable  $\kappa$ :*

- (i):  $\kappa < \kappa(T)$ , see e.g. 2.1(1),
- (ii): *there is a non-saturated  $\kappa$ -resplendent model of  $T$  (see Definition 1.4 below),*
- (iii): *for every  $\lambda = \lambda^\kappa \geq 2^{|T|}$ ,  $T$  has  $> \lambda$  non-isomorphic  $\kappa$ -resplendent models,*
- (iv): *for every  $\lambda = \lambda^\kappa \geq 2^{|T|}$ ,  $T$  has  $2^\lambda$  non-isomorphic  $\kappa$ -resplendent models.*

Proof: The implication (i)  $\Rightarrow$  (iii) follows from the main Lemma 1.9 below; the implication (iii)  $\Rightarrow$  (ii) is trivial, and (ii)  $\Rightarrow$  (i) follows from 1.8 below. Lastly, trivially (iv)  $\Rightarrow$  (iii) and (i)  $\Rightarrow$  (iv) by 3.1+2.22.

**Remark 1.3.** (1) If we omit condition (iv) we save §3 as well as the dependency on a theorem from [Sh:309] using only an easy relative.  
 (2) In the proof the main point is (i)  $\Rightarrow$  (iii) (and (i)  $\Rightarrow$  (iv), i.e., the non-structure part).  
 (3) Remember:  $T$  is unstable iff  $\kappa(T) = \infty$ .  
 (4) Notice that every saturated model  $M$  is  $\|M\|$ -resplendent (see 1.4(2) below). Actually a little more.

**Definition 1.4.** (1): *A model  $M$  is  $(\kappa, \ell)$ -resplendent (where  $\ell = 0, 1, 2, 3$ ) if: for every elementary extension  $N$  of  $M$  and expansion  $N_1$  of  $N$  satisfying  $|\tau(N_1) \setminus \tau(N)| < \kappa$  and  $\alpha < \kappa$ ,  $c_i \in M$  for  $i < \alpha$  and  $T_1 \subseteq \text{Th}(N_1, c_i)_{i < \alpha}$  satisfying  $(*)_{T_1}^\ell$  below, there is an expansion  $(M_1, c_i)_{i < \alpha}$  of  $(M, c_i)_{i < \alpha}$  to a model of  $T_1$ , when:*

- $(*)_{T_1}^\ell$ : **Case 0:**  $\ell = 0$ :  $|T_1| < \kappa$ ,  
**Case 1:**  $\ell = 1$ : for some  $\tau' \subseteq \tau(N_1)$ ,  $|\tau'| < \kappa$  and  $T_1 \subseteq \mathbb{L}(\tau' \cup \{c_i : i < \alpha\})$ ,  
**Case 2:**  $\ell = 2$ :  $T_1$  is  $\kappa$ -recursive (see 1.4(4) below),  
**Case 3:**  $\ell = 3$ :  $T_1 = \text{Th}(N_1, c_i)_{i < \alpha}$  (but remember that  $N_1$  has only  $< \kappa$  relations and functions not of  $M$ ).

- (2):  $\kappa$ -resplendent means  $(\kappa, 3)$ -resplendent.
- (3): Assume  $M$  is a model of  $T$ ,  $\bar{c} \in {}^{\kappa>}M$  and  $M_{\bar{c}}$  is an expansion of  $(M, \bar{c})$ . We say that  $M_{\bar{c}}$  witnesses  $(\kappa, \ell)$ -resplendence for  $\bar{c}$  in  $M$ , when:  
 for every first order  $T_1$  such that

$$\text{Th}(M, \bar{c}) \subseteq T_1 \quad \& \quad |\tau(T_1) \setminus \tau(T)| < \kappa$$

and  $(*)_{T_1}^\ell$  holds, we have:

$M_{\bar{c}}$  is a model of  $T_1$  up to renaming the symbols in  $\tau(T_1) \setminus \tau(M, \bar{c})$ .

- (4): For  $M, N_1$ ,  $\langle c_i : i < \alpha \rangle$  and  $T_1 \subseteq \text{Th}(N_1, c_i)_{i < \alpha}$  as in part (1),  $T_1$  is  $\kappa$ -recursive when:

(a):  $\kappa = \aleph_0$  and  $T_1$  is recursive (assuming the vocabulary of  $T$  is represented in a recursive way or

(b):  $\kappa > \aleph_0$  and for some  $\tau^* \subseteq \tau(N_1)$ ,  $|\tau^*| < \kappa$  the following holds:  
if  $\varphi_\ell(x_0, \dots, x_{n-1}) \in \mathbb{L}(\tau')$  for  $\ell = 1, 2$  and there is an automorphism  $\pi$  of  $\tau'$  (see parts (9)), where  $\tau^* \subseteq \tau' \subseteq \tau(N_1)$  such that  $\pi$  is the identity on  $\tau^*$  and  $\hat{\pi}(\varphi_1) = \varphi_2$  and  $\beta_0 < \beta_1 < \dots < \alpha$  then

$$\varphi_1(c_{\beta_0}, c_{\beta_1}, \dots) \in T_1 \quad \text{iff} \quad \varphi_2(c_{\beta_0}, c_{\beta_1}, \dots) \in T_1.$$

(5): We say  $f$  is an  $(M, N)$ -elementary mapping when  $f$  is a partial one-to-one function from  $M$  to  $N$ ,  $\tau(M) = \tau(N)$  and for every  $\varphi(x_0, \dots, x_{n-1}) \in \mathbb{L}(\tau(M))$  and  $a_0, \dots, a_{n-1} \in M$  we have:

$$M \models \varphi[a_0, \dots, a_{n-1}] \quad \text{iff} \quad N \models \varphi[f(a_0), \dots, f(a_{n-1})].$$

(6):  $f$  is an  $M$ -elementary mapping if it is an  $(M, M)$ -elementary mapping.

(7):  $M$  is  $\kappa$ -homogeneous if :

for any  $M$ -elementary mapping  $f$  with  $|\text{Dom}(f)| < \kappa$  and  $a \in M$  there is an  $M$ -elementary mapping  $g$  such that:

$$f \subseteq g, \quad \text{Dom}(g) = \{a\} \cup \text{Dom}(f).$$

(8):  $M$  is strongly  $\kappa$ -homogeneous if for any  $M$ -elementary mapping  $f$  with  $|\text{Dom}(f)| < \kappa$  there is an automorphism  $g$  of  $M$ , such that  $f \subseteq g$ .

(9): Let  $\tau_1 \subseteq \tau_2$  be vocabularies. We say that  $\pi$  is an automorphism of  $\tau_2$  over  $\tau_1$  when:  $\pi$  is a permutation of  $\tau_2$ ,  $\pi$  maps any predicate  $P \in \tau_2$  to a predicate of  $\tau_2$  with the same arity,  $\pi$  maps any function symbol of  $F \in \tau_2$  to a function symbol of  $\tau_2$  of the same arity and  $\pi|_{\tau_1}$  is the identity.

(10): For  $\pi, \tau_2$  as in part (9) let  $\hat{\pi}$  be the permutation of the set of formulas in the vocabulary  $\tau_2$  which  $\pi$  induce.

**Example 1.5.** There is, for each regular  $\kappa$ , a theory  $T_\kappa$  such that:

(a):  $T_\kappa$  is superstable of cardinality  $\kappa$ ,

(b): for  $\lambda \geq \kappa$ ,  $T_\kappa$  has  $2^\lambda$  non-isomorphic  $(\kappa, 1)$ -resplendent models.

Note:

**Fact 1.6.** (1) If  $\tau = \tau(M)$ , and

$$[\tau' \subseteq \tau \ \& \ |\tau'| < \kappa \quad \Rightarrow \quad M \restriction \tau' \text{ is saturated}]$$

then  $M$  is  $(\kappa, 1)$ -resplendent.

(2) If  $M$  is saturated of cardinality  $\lambda$  then  $M$  is  $\lambda$ -resplendent.

Proof: Easy, e.g., see [Sh:a] and not used here elsewhere.

Proof of 1.5: Let  $A_0 = \{\kappa \setminus (i+1) : i < \kappa\}$  and  $A_1 = A_0 \cup \{\emptyset\}$ . For every linear order  $I$  of cardinality  $\lambda \geq \kappa$  we define a model  $M_I$ :

its universe is

$$I \cup \{\langle s, t, i, x \rangle : s \in I, t \in I, i < \lambda, x \in A_1 \text{ and } [I \models s < t \Rightarrow x \in A_0]\},$$

(and of course, without loss of generality, no quadruple  $\langle s, t, i, x \rangle$  as above belongs to  $I$ ), its relations are:

$$\begin{aligned} P &= I, \\ R &= \{\langle s, t, \langle s, t, i, x \rangle \rangle : s \in I, t \in I, \langle s, t, i, x \rangle \in |M_I| \setminus P\}, \\ Q_\alpha &= \{\langle s, t, i, x \rangle : \langle s, t, i, x \rangle \in |M_I| \setminus P, \alpha \in x\} \quad \text{for } \alpha < \kappa. \end{aligned}$$

In order to have the elimination of quantifiers we also have two unary functions  $F_1, F_2$  defined by:

$$\begin{aligned} s \in I &\Rightarrow F_1(s) = F_2(s) = s, \\ \langle s, t, i, x \rangle \in |M_I| \setminus I &\Rightarrow F_1(\langle s, t, i, x \rangle) = s \& F_2(\langle s, t, i, x \rangle) = t. \end{aligned}$$

It is easy to see that:

(a): In  $M_I$ , the formula

$$P(x) \& P(y) \& (\exists z)(R(x, y, z) \& \bigwedge_{\alpha < \kappa} \neg Q_\alpha(z))$$

linearly orders  $P^{M_I}$ , in fact defines  $<_I$ ;

(b):  $\text{Th}(M_I)$  has elimination of quantifiers;

(c): if  $\tau \subseteq \tau(M_I)$ ,  $|\tau| < \kappa$  then  $M_I \upharpoonright \tau$  is saturated;

(d):  $\text{Th}(M_I)$  does not depend on  $I$  (as long as it is infinite) and we call it  $T_\kappa$ ;

(e):  $T_\kappa$  is superstable.

Hence:  $T_\kappa = \text{Th}(M_I)$  is superstable, does not depend on  $I$ , and

$$M_I \cong M_J \quad \text{if and only if} \quad I \cong J,$$

and by 1.6  $M_I$  is  $(\kappa, 1)$ -resplendent. ■1.6

**Fact 1.7.** (1)  $M$  is  $(\kappa, 3)$ -resplendent implies  $M$  is  $(\kappa, \ell)$ -resplendent implies  $M$  is  $(\kappa, 0)$ -resplendent.

(2)  $M$  is  $(\kappa, 0)$ -resplendent implies  $M$  is  $\kappa$ -compact.

(3)  $M$  is  $(\kappa, 2)$ -resplendent implies  $M$  is  $\kappa$ -homogeneous, even strongly  $\kappa$ -homogeneous (see Definition 1.4(7),(8)).

(4) If  $M$  is  $(\kappa, 2)$ -resplendent  $\kappa > \aleph_0$  and  $\{\bar{a}_n : n < \omega\}$  is an indiscernible set in  $|M|$ , then it can be extended to an indiscernible set of cardinality  $\|M\|$  (similarly for sequences).

(5)  $M$  is  $(\kappa, 3)$ -resplendent implies  $M$  is  $\kappa$ -saturated.

(6) If  $\kappa > |T|$  then the notions of 1.4 “ $(\kappa, \ell)$ -resplendent” for  $\ell = 0, 1, 2, 3$ , are equivalent.

Proof: Straightforward, for example

(3) For given  $a_i, b_i \in M$  (for  $i < \alpha$ , where  $\alpha < \kappa$ ) let

$$\begin{aligned} T_1 = & \{g(a_i) = b_i : i < \alpha\} \cup \\ & \{(\forall x, y)(g(x) = g(y) \Rightarrow x = y), (\forall x)(\exists y)(g(y) = x)\} \cup \\ & \{(\forall x_0, \dots, x_{n-1})[R(x_0, \dots, x_{n-1}) \equiv R(g(x_0), \dots, g(x_{n-1}))]\} : \\ & \quad R \text{ an } n\text{-place predicate of } \tau(M)\} \cup \\ & \{(\forall x_0, \dots, x_{n-1})[F(g(x_0), \dots) = g(F(x_0, \dots))]\} : \\ & \quad F \text{ an } n\text{-place function symbol of } \tau(M)\}. \end{aligned}$$

(4) For notational simplicity let  $\bar{a}_n = a_n$ . Let  $T_1$  be, with  $P$  a unary predicate,  $g$  a unary function symbol,

$$\begin{aligned} & \{“g \text{ is a one-to-one function into } P”\} \cup \{P(a_n) : n < \omega\} \cup \\ & \{(\forall x_0, \dots, x_{n-1}) \left[ \bigwedge_{\ell < n} P(x_\ell) \& \bigwedge_{\ell < m < n} x_\ell \neq x_m \& \varphi[a_0, \dots, a_{n-1}] \right. \\ & \quad \left. \Rightarrow \varphi(x_0, \dots, x_{n-1}) \right]\} : \\ & \quad \varphi(x_0, \dots, x_{n-1}) \in \mathbb{L}(\tau(M)) \} \end{aligned}$$

■1.7

**Conclusion 1.8.** *If  $M$  is  $\kappa$ -resplendent,  $\kappa \geq \kappa(T) + \aleph_1$  then  $M$  is saturated.*

Proof: By 1.7(5)  $M$  is  $\kappa$ -saturated, so without loss of generality  $\|M\| > \kappa$ . Hence, by [Sh:a] or [Sh:c, III,3.10(1),p.107], it is enough to prove: for  $\dot{\mathbf{I}}$  an infinite indiscernible  $\subseteq M$ ,  $\dim(\dot{\mathbf{I}}, M) = \|M\|$ . But this follows by 1.7(4). ■1.8

**Main Lemma 1.9.** *Suppose that  $\kappa = \text{cf}(\kappa) < \kappa(T)$  (for example,  $T$  unstable,  $\kappa$  regular) and  $\lambda = \lambda^\kappa + 2^{|T|}$ . Then  $T$  has  $> \lambda$  pairwise non-isomorphic  $\kappa$ -resplendent models of cardinality  $\lambda$ .*

Before embarking on the proof, we give some explanations.

- Remark 1.10.** (1) We conjecture that we can weaken in 1.9 the hypothesis “ $\lambda = \lambda^\kappa + 2^{|T|}$ ” to “ $\lambda = \lambda^{<\kappa} + 2^{|T|}$ ”. This holds for many  $\lambda$ 's, see [Sh:309, §2]; but we have not looked at this. See §3.
- (2) We naturally try to imitate [Sh:a], [Sh:c, VII,§2, VIII,§2] or [Sh:E59, §3], [Sh:331]. In the proof of the theorem, the difficulty is that while expanding to take care of resplendency, we naturally will use Skolem functions with infinite arity, and so we cannot use compactness so easily.

If the indiscernibility is not clear, the reader may look again at [Sh:a] or [Sh:c, VII,§2], (tree indiscernibility). We get below first a weaker version of indiscernibility, as it is simpler to get it, and is totally harmless if we would like just to get  $> \lambda$  non-isomorphic models by the old version [Sh:300, III,4.2(2)] or the new [Sh:309, §2]

**Explanation 1.11.** Note that the problem is having to deal with sequences of  $< \kappa$  elements  $\bar{b} = \langle b_i : i < \epsilon \rangle$ ,  $\epsilon$  infinite. The need to deal with such  $\bar{b}$  with all theories of small vocabulary is not serious – there is a “universal one” though possibly of larger cardinality, i.e., if  $M \models T$ ,  $b_i \in M$  for  $i < \epsilon$ ,  $\epsilon < \kappa$ , we can find a f.o. theory  $T_2 = T_2(\bar{b})$  satisfying  $\text{Th}(M, b_{i < \epsilon}) \subseteq T_1$ ,  $|T_1| \leq (2^{|T|+|\epsilon|})^{<\kappa}$  such that:

if  $\text{Th}(M, b_{i < \epsilon}) \subseteq T'$  and  $|\tau(T') \setminus \tau(T) \setminus \{b_i : i < \epsilon\}| < \kappa$   
then renaming the predicates and function symbols outside  $T$ , we  
 get  $T' \subseteq T_2(\bar{b})$

– this is possible by Robinson consistency lemma. Let us give more details.

**Claim 1.12.** (1) *Let  $M_0$  be a model,  $\tau_0 = \tau(M_0)$ ,  $\bar{b} = \langle b_i : i < \kappa \rangle$  where  $b_i \in M_0$  for  $i < \epsilon$  and  $\theta \geq \aleph_0$  be a cardinal. Let  $\tau_1 = \tau_0 \cup \{b_i : i < \epsilon\}$  so  $M_1 = (M_0, b_{i < \epsilon})$  is a  $\tau_1$ -model. Then there is a theory  $T_2 = T_2[\bar{b}] = T_2[\bar{b}, M]$ , depending only on  $\tau_0$ ,  $\tau_1$  and  $\text{Th}(M_1)$ , i.e., essentially on  $\text{tp}(\langle b_i : i < \epsilon \rangle, \emptyset, M_0)$  such that:*

- (a):  $\tau_2 = \tau(T_2) = \tau(\epsilon, \tau_0)$  extends  $\tau_1$  and has cardinality  $\leq 2^{|\tau_1|+\theta+|\epsilon|}$ ,  
 (b): for every  $M_2$ ,  $T'$ , the model  $M_2$  is expandable to a model of  $T'$ ,  
when:

- (α):  $M_2$  is a  $\tau_1$ -model,  
 (β):  $M_2$  can be expanded to a model of  $T_2$ ,  
 (γ):  $\text{Th}(M_2) \subseteq T'$ , equivalently some elementary extension of  $M_2$  is expandable to a model of  $T'$ ,  
 (δ):  $T'$  is f.o. and  $|\tau(T') \setminus \tau(M_2)| \leq \theta$ ,  
 (a)<sup>+</sup>: if  $\theta > |T| + |\epsilon|$  then  $|\tau_2| \leq 2^{<\theta}$  is enough.
- (2) *If in part (1), clause (δ) of (b) is weakened to*

- ( $\delta$ )<sub>2</sub>:  $T'$  is f.o., and  $|\tau(T') \setminus \tau(M_2)| < \theta$ ,  
then we can strengthen (a) to  
 (a)<sub>2</sub>:  $\tau_2 = \tau(T_2)$  extends  $\tau_1$  and has cardinality  $\leq \sum_{\mu < \theta} 2^{|\tau_1| + \mu + \aleph_0 + |\varepsilon|}$ ,  
 (a)<sub>2</sub><sup>+</sup>: if  $\theta > (|T| + |\varepsilon|)^+$  then  $|\tau_2| \leq \sum_{\mu < \theta} 2^{< \mu}$  is enough.

Proof: 1) We ignore function symbols and individual constants as we can replace them by predicates. Let

$$\mathbb{T} = \{T' : T' \text{ f.o. complete theory, } \text{Th}(M_1) \subseteq T' \text{ and } |\tau(T') \setminus \tau(M_1)| \leq \theta\}.$$

This is a class; we say that  $T', T'' \in \mathbb{T}$  are isomorphic over  $\text{Th}(M_1)$  (see [Sh:8]) when there is a function  $\mathbf{h}$  satisfying:

- (a):  $\mathbf{h}$  is one-to-one,
- (b):  $\text{Dom}(\mathbf{h}) = \tau(T')$ ,
- (c):  $\text{Rang}(\mathbf{h}) = \tau(T'')$ ,
- (d):  $\mathbf{h}$  preserves arity (i.e., the number of places, and of course being predicate/function symbols),
- (e):  $\mathbf{h} \upharpoonright (\tau(M_1)) = \text{identity}$ ,
- (f): for a f.o. sentence  $\psi = \psi(R_1, \dots, R_k) \in \mathbb{L}[\tau(\mathbf{T}')]$ , where  $R_1, \dots, R_k$  are the non-logical symbols occurring in  $\psi$ , we have

$$\psi(R_1, \dots, R_k) \in T' \Leftrightarrow \psi(\mathbf{h}(R_1), \dots, \mathbf{h}(R_k)) \in T''.$$

Now note that

$$\boxplus_1 \mathbb{T} / \cong \text{ has cardinality } \leq 2^{|\tau_0| + |\varepsilon| + \theta}.$$

Now let  $\{T'_\alpha : \alpha < 2^{|\tau_0| + |\varepsilon| + \theta}\}$  list members of  $\mathbb{T}$  such that every equivalence class of being isomorphic over  $\text{Th}(M_1)$  is represented.  $\langle \tau(T'_\alpha) \setminus \tau_1 : \alpha < 2^{|\tau_0| + |\varepsilon| + \theta} \rangle$  are pairwise disjoint.

Note that  $\text{Th}(M_1) \subseteq T'_\alpha$ . Let  $T'_2 = \bigcup \{T'_\alpha : \alpha < 2^{|\tau_0| + |\varepsilon| + \theta}\}$  and

$\boxplus_2 T'_2$  is consistent.

Why? By Robinson consistency theorem.

Let  $T_2$  be any completion of  $T'_2$ . So condition (a) holds; proving (b) should be easy.

Let us prove (a)<sup>+</sup>; this is really the proof that a theory  $T$ ,  $|T| < \theta$ , has a model in  $2^{< \theta}$  universal for models of  $T$  of cardinality  $\leq \theta$ . We shall define by induction on  $\alpha < \theta$ , a theory  $T_\alpha^2$  such that:

- (A):  $T_0^2 = \text{Th}(M_1)$ ,
- (B):  $T_\alpha^2$  a f.o. theory,
- (C):  $\tau_\alpha^2 = \tau(T_\alpha^2)$  has cardinality  $\leq 2^{|\tau_0| + |\varepsilon| + |\alpha| + \aleph_0}$ ,
- (D):  $T_\alpha^2, \tau_\alpha^2$  are increasing continuous in  $\alpha$ ,
- (E): if  $\tau_1 \subseteq \tau' \subseteq \tau_\alpha^2$ ,  $|\tau'| \leq |\tau^1| + |\alpha|$ ,  $\tau' \subseteq \tau''$ ,  $\tau'' \cap \tau_\alpha^2 = \tau'$ ,  $T_\alpha^2 \upharpoonright \mathbb{L}_{\tau'} \subseteq T'' \subseteq \mathbb{L}[\tau'']$ ,  $T''$  complete and  $|\tau'' \setminus \tau'| = \{R\}$ ,  
then we can find  $R' \in \tau_{\alpha+1}^2 \setminus \tau_\alpha^2$  such that of the same arity.

$$T''[\text{replacing } R \text{ by } R'] \subseteq T_{\alpha+1}^2$$

There is no problem to carry out the induction, and  $\bigcup_{\alpha < \theta} T_\alpha^2$  is as required.

2) Similar.

■1.12

**Explanation 1.13.** So for  $M \models T$ ,  $\bar{b} \in {}^{\kappa}M$ , we can choose  $T_1[\bar{b}] \supseteq \text{Th}(M, \bar{b})$  depending on  $\text{Th}(M, \bar{b})$  only, such that:

( $\otimes$ ):  $M \models$  “ $T$  is  $\kappa$ -resplendent iff for every  $\bar{b} \in {}^{\kappa}M$ ,  $(M, \bar{b})$  is expandable to a model of  $T_2[\bar{b}]$ .”

W.l.o.g.  $\tau(T_2[\bar{b}])$  depends on  $\text{lg}(\bar{b})$  and  $\tau_0$  only, so it is  $\tau(\text{lg}(\bar{b}), \tau_M)$ .

The things look quite finitary but  $T_2[\bar{b}]$  is not continuous in  $\text{Th}(M, \bar{b})$ . I.e.,

(\*)  $\not\equiv$  (\*\*), where

(\*) :  $\bar{b}^\alpha \in {}^{\kappa}M$ , for  $\alpha \leq \delta$ , ( $\delta$  a limit ordinal)  $\text{lg}(\bar{b}^\alpha) = \epsilon$ , and for every  $n$ ,  $i_1 < \dots < i_n < \epsilon$  and a formula  $\varphi(x_{i_1}, \dots, x_{i_n}) \in \mathbb{L}(\tau_M)$  for some  $\beta < \delta$ :

$$\beta \leq \alpha \leq \delta \quad \Rightarrow \quad M \models \varphi[b_{i_1}^\beta, \dots, b_{i_n}^\beta] \equiv \varphi[b_{i_1}^\alpha, \dots, b_{i_n}^\alpha],$$

(\*\*) : for any  $\varphi \in \mathbb{L}(\tau_2)$  for some  $\beta < \delta$ :

$$\beta \leq \alpha \leq \delta \quad \Rightarrow \quad [\varphi \in T_2[\bar{b}^\alpha] \Leftrightarrow \varphi \in T_2[\bar{b}^\beta]].$$

[You can make  $T_1[\bar{b}]$  somewhat continuous function of the sequence  $\bar{b}$  if we look at sub-sequences as approximations, not the type, but this is not used.]

*This explain Why you need “infinitary Skolem functions”.*

We shall try to construct  $M$  such that for every  $\bar{b} \in {}^\epsilon M$ ,  $(M, \bar{b})$  is expandable to a model of  $T_2[\bar{b}]$ , so if  $\tau_2^\epsilon = \tau(T_2[\bar{b}]) \setminus \tau(M, \bar{b})$ , this means we have to define finitary relations/functions  $R_{\bar{b}}$  (for  $R \in \tau_2^\epsilon$ ). We write here  $\bar{b}$  as a sequence of parameters but from another prospective the predicate/function symbol  $R_{\square}(-)$  has  $\epsilon + \text{arity}(R)$ -places.

**Explaining the first construction 1.14.** (i.e., 2.19 below)

Eventually we build a generalization of  $\text{EM}(\kappa \geq \lambda, \Psi)$ , a model with skeleton  $\bar{a}_\eta$  ( $\eta \in {}^{\kappa} \geq \lambda$ ) witnessing  $\kappa < \kappa(T)$ , but the functions have any  $\alpha < \kappa$  places but not  $\kappa$ , and the indiscernibility demands is weak. We start as in [Sh:E59, §2], so for some formulas  $\langle \varphi_\alpha(x, \bar{y}, \alpha) : \alpha < \kappa \rangle$  we have (where  $\bar{a}_\eta = \langle a_\eta \rangle$  for  $\eta \in {}^{\kappa} \lambda$ ):

$$\eta \in {}^{\kappa} \lambda \ \& \ \nu \in {}^{\alpha+1} \lambda \quad \Rightarrow \quad \varphi_\alpha(a_\eta, \bar{a}_\nu)^{\text{if}(\nu \triangleleft \eta)}.$$

Without loss of generality, for any  $\alpha < \kappa$  for some sequence  $\bar{G}_\alpha = \langle G_{\alpha, \ell} : \ell < \text{lg}(\bar{y}_\alpha) \rangle$  of unary function symbols for any  $\eta \in {}^{\kappa} \lambda$ ,  $\bar{a}_\eta \restriction \alpha = \bar{G}_\alpha(a_\eta) := \langle G_{\alpha, \ell}(a_\eta) : \ell < \text{lg}(\bar{y}_\alpha) \rangle$ , so we can look at  $\{a_\eta : \eta \in {}^{\kappa} \lambda\}$  as generators. For  $W \in [{}^{\kappa} \lambda]^{< \kappa}$ , let  $N_W = N[W]$  be the submodel which  $\{a_\eta : \eta \in W\}$  generates. So we would like to have:

( $\alpha$ ):  $N_W$  has the finitary Skolem function (for  $T$ ), and moreover

$N_W$  has the finitary Skolem function for  $T_2[\bar{b}]$  for each  $\bar{b} \in {}^{\kappa} (N_W)$ ,

( $\beta$ ): monotonicity:  $W_1 \subseteq W_2 \Rightarrow N_{W_1} \subseteq N_{W_2}$ .

So if  $\mathcal{W} \subseteq {}^{\kappa} \lambda$ , then  $N[\mathcal{W}] = \{N_W : W \in {}^{\kappa} [\mathcal{W}]\}$  is a  $\kappa$ -resplendent model of cardinality  $\lambda$ .

( $\gamma$ ): Indiscernibility: (We use here very “minimal” requirement (see below) but still enough for the omitting type in (1) below):

(1):  $\eta \in {}^{\kappa} \lambda \setminus \mathcal{W} \Rightarrow N[\mathcal{W}]$  omits  $p_\eta =: \{\varphi_\alpha(x, \bar{a}_\eta \restriction \alpha) : \alpha < \kappa\}$ ; (satisfaction defined in  $N[{}^{\kappa} \lambda]$ ),

(2):  $\eta \in {}^{\kappa} \lambda \cap \mathcal{W} \Rightarrow N[\mathcal{W}]$  realizes  $p_\eta$ .

Now (2) was already guaranteed:  $a_\eta$  realizes  $p_\eta$ .

For (1) it is enough



(1)': if  $W \in {}^{\kappa>}[\kappa\lambda]$ ,  $\eta \in {}^{\kappa}\lambda \setminus W$  then  $p_\eta$  is omitted by  $N_W$  (satisfaction defined in  $N[{}^{\kappa\geq}\lambda]$ ).

Fix  $W, \eta$  for (1)'. A sufficient condition is

(1)'': for  $\alpha < \kappa$  large enough,  $\langle \bar{a}_{\eta \upharpoonright \alpha \smallfrown \langle i \rangle} : i < \lambda \rangle$  is indiscernible over  $N_W$  in  $N[{}^{\kappa}]$ .

[if  $\kappa_r(T) < \infty$ , immediately suffices; in the general case, and avoiding classification theory, use

$$p'_\eta = \{\varphi_\alpha(x, \bar{a}_{\eta \upharpoonright (\alpha+1)}) \ \& \ \neg\varphi(x, \bar{a}_{\eta \upharpoonright \alpha \smallfrown \langle \eta(\alpha)+1 \rangle}) : \alpha < \kappa\}$$

so we use

$$\varphi'(x, \bar{y}'_\alpha) = \varphi_\alpha(x, \bar{y}'_\alpha \upharpoonright \ell g(\bar{y}_\alpha)) \wedge \neg\varphi_\alpha(x, \bar{y}'_\alpha \upharpoonright (\ell g(\bar{y}_\alpha), 2 \ell g(\bar{y}_\alpha)))$$

in the end].

Note: as  $|W| < \kappa$ , for some  $\alpha(*) < \kappa$ , for every  $\eta \in {}^{\kappa}\lambda$

$$W \cap \{\nu : \eta \upharpoonright \alpha(*) \triangleleft \nu \in {}^{\kappa}\lambda\} \text{ is a singleton}$$

and  $W \in \mathbf{W}_{\alpha(*)}$  (see below), this will be enough to omit the type. The actual indiscernibility is somewhat stronger.

Farther Explanation: On the one hand, we would like to deal with arbitrary sequences of length  $< \kappa$ , on the other hand, we would like to retain enough freedom to have the weak indiscernibility. What do we do? We define our “ $\Phi$ ” (not as nice as in [Sh:E59, §2], i.e., [Sh:a, Ch.VII §3]) by  $\kappa$  approximations indexed by  $\alpha \leq \kappa$ .

For  $\alpha \leq \kappa$ , we essentially have  $N_W$  for

$$W \in \mathbf{W}_\alpha =: \{W : \begin{array}{l} W \subseteq {}^{\kappa\geq}\lambda, \ |W| < \kappa \text{ and} \\ \text{the function } \eta \mapsto \eta \upharpoonright \alpha \ (\eta \in W) \text{ is one-to-one} \end{array}\}.$$

Now,  $\mathbf{W}_\alpha$  is partially ordered by  $\subseteq$  but (for  $\alpha < \kappa$ ) is not directed. For  $\alpha < \beta$  we have  $\mathbf{W}_\alpha \subseteq \mathbf{W}_\beta$  and  $\mathbf{W}_\kappa = \bigcup_{\alpha < \kappa} \mathbf{W}_\alpha$  is equal to  $[{}^{\kappa\geq}\lambda]^{<\kappa}$ .

So if we succeed to carry out the induction for  $\alpha < \kappa$ , arriving to  $\alpha = \kappa$  the direct limit works and no new sequence of length  $< \kappa$  arises.

## 2. PROOF OF THE MAIN LEMMA

In this section we get many models using a weak version of indiscernibility.

**Context 2.1.** (1)  $T$  is a fix complete first order theory,  $\kappa < \kappa(T)$ ,  $\bar{\varphi} = \langle \varphi_\alpha(x, y) : \alpha < \kappa \rangle$  is a fixed witness for  $\kappa < \kappa(T)$ , that is  
 (\*): for any  $\lambda$ , for some model  $M$  of  $T$  and sequence  $\langle a_\eta : \eta \in {}^\kappa \lambda \rangle$  with  $a_\eta \in M$  we have: if  $\epsilon < \kappa$ ,  $\eta \in {}^\kappa \lambda$ ,  $\alpha < \lambda$  then  $M \models \varphi_\epsilon[a_\eta, a_{\eta \restriction \epsilon \cap \langle \alpha \rangle}]^{\text{if}(\alpha = \eta(\epsilon))}$ .  
 (2) Let  $\mu$  be infinite large enough cardinal;  $\mu = \beth_\omega(|T|)$  is O.K.

REMARK: Why are we allowed in 2.1(1) to use  $\varphi_\alpha(x, y)$  instead  $\varphi(x, \bar{y})$ ? We can work in  $T^{\text{eq}}$ , see [Sh:c, Ch. III] and anyhow this is, in fact, just a notational change.

**Definition 2.2.** (1) For  $\alpha < \kappa$  and  $\rho \in {}^\alpha \mu$ , let  $I_\rho = I_\rho^\alpha = I_\rho^{\alpha, \mu}$  be the model  
 $(\{\nu \in ({}^\kappa \mu) : \nu \restriction \alpha = \rho\}, E_i <_i)_{i < \kappa}$ ,

where

$$\begin{aligned} E_i &= \{(\eta, \nu) : \eta \in {}^\kappa \mu, \nu \in {}^\kappa \mu, \eta \restriction i = \nu \restriction i\}, \\ <_i &= \{(\eta, \nu) : \eta \restriction E_i \nu \text{ and } \eta(i) < \nu(i)\}. \end{aligned}$$

- (2) Let  $\mathbf{W}_\alpha = \mathbf{W}_\alpha^\mu = \{W \subseteq {}^\kappa \mu : W \text{ has cardinality } < \kappa \text{ and for any } \eta \neq \nu \text{ from } W \text{ we have } \eta \restriction \alpha \neq \nu \restriction \alpha\}$ , and  $\mathbf{W}_{<\alpha} = \bigcup_{\beta < \alpha} \mathbf{W}_\beta$ .  
 (3) We say that  $\mathbf{W}$  is  $\alpha$ -invariant, or  $(\alpha, \mu)$ -invariant, when  $\mathbf{W} \subseteq \mathbf{W}_\alpha$  and:  
if  $W_1, W_2 \in \mathbf{W}_\alpha$ ,  $h$  is a one-to-one function from  $W_1$  onto  $W_2$  and  $\eta \restriction \alpha = h(\eta) \restriction \alpha$  for  $\eta \in W_1$ ,  
then  $W_1 \in \mathbf{W} \Leftrightarrow W_2 \in \mathbf{W}$ .  
 (4) We say  $\mathbf{W} \subseteq \mathbf{W}_\alpha$  is hereditary if it  $W' \subseteq W \in \mathbf{W} \Rightarrow W' \in \mathbf{W}$

**Definition 2.3.** (1) Let  $\theta = \theta_{T, \kappa}$  be the minimal cardinal satisfying:

- (a):  $\theta = \theta^{<\kappa} \geq |T|$ ,  
 (b): if  $M$  is a model of  $T$ ,  $\bar{b} \in {}^{<\kappa} M$ , then there is a complete (first order) theory  $T^*$  with Skolem functions extending  $\text{Th}(M, \bar{b})$  such that:  
 if  $T' \supseteq \text{Th}(M, \bar{b})$  and  $\tau(T') \setminus \tau_{(M, \bar{b})}$  has cardinality  $< \kappa$   
then there is a one-to-one mapping from  $\tau(T')$  into  $\tau(T^*)$  over  $\tau_{(M, \bar{b})}$  preserving arity and being a predicate / function symbol, and mapping  $T'$  into  $T^*$ .

- (2) For  $\varepsilon < \kappa$ , let  $\tau[T, \varepsilon]$  be a vocabulary consisting of  $\tau_T$ , the individual constants  $\underline{b}_\xi$  for  $\xi < \varepsilon$ , and the  $n$ -place predicates  $R_{T, j, n}$  for  $j < \theta$  and  $n$ -place function symbols  $F_{T, j, n}$  for  $j < \theta$ .

For  $\varepsilon < \kappa$  and a complete theory  $T^\oplus$  in the vocabulary  $\tau_T \cup \{\underline{b}_\xi : \xi < \varepsilon\}$  extending  $T$ , let  $T^*[T^\oplus]$  be a complete first order theory in the vocabulary  $\tau[T, \varepsilon]$  such that if  $(M, \bar{b})$  is a model of  $T^\oplus$ , then  $T^*[T^\oplus]$  is as in clause (b) of part (1).

- (3) For  $M \models T$  and  $\varepsilon < \kappa$  and  $\bar{b} \in {}^\varepsilon M$ , let  $T^*[\bar{b}, M] = T^*[\text{Th}(M, \bar{b})]$ .

**Remark 2.4.** Note that  $\theta$  is well defined by 1.12. In fact,  $\theta = \Pi\{2^{|T|+\sigma} : \sigma^+ < \kappa\}$  is OK.

**Main Definition 2.5.** We say that  $\mathbf{m}$  is an approximation (or an  $\alpha$ -approximation, or  $(\alpha, \mu)$ -approximation) if

$$(*)_1: \alpha \leq \kappa \text{ (so } \alpha = \alpha_{\mathbf{m}} = \alpha(\mathbf{m})),$$

(\*)<sub>2</sub>:  $\mathbf{m}$  consists of the following (so we may give them subscript or superscript  $\mathbf{m}$ ):

- (a): a model  $M = M_{\mathbf{m}}$ ;
- (b): a set  $\mathcal{F} = \mathcal{F}_{\mathbf{m}}$  of symbols of functions, each  $f \in \mathcal{F}$  has an interpretation, a function  $f_{\mathbf{m}}$  with range  $\subseteq M$ , but when no confusion arises we may write  $f$  instead of  $f_{\mathbf{m}}$ , (or  $f^{\mathbf{m}}$ , note that the role of those  $f$ -s is close to that of function symbols in vocabularies, but not equal to);
- (c): each  $f \in \mathcal{F}$  has  $\zeta_f < \kappa$  places, to each place  $\zeta$  (i.e., an ordinal  $\zeta < \zeta_f$ ) a unique  $\eta_{\zeta} \in {}^{\alpha}\mu$ ,  $\eta_{\zeta} = \eta_{\zeta}^f = \eta(f, \zeta)$  is attached such that

$$[\zeta \neq \xi \Rightarrow \eta_{\zeta} \neq \eta_{\xi}],$$

and the  $\zeta$ -th variable of  $f$  varies on  $I_{\eta_{\zeta}}$ , i.e.,  $f_{\mathbf{m}}(\dots, x_{\zeta}, \dots)_{\zeta < \zeta_f}$  is well defined iff  $\bigwedge_{\zeta < \zeta_f} x_{\zeta} \in I_{\eta_{\zeta}} = I_{\eta_{\zeta}}^{\alpha, \mu}$ ;

we may write  $f_{\mathbf{m}}(\dots, \nu_{\eta}, \dots)_{\eta \in w[f]}$  instead  $f_{\mathbf{m}}(\dots, \nu_{\eta(f, \zeta)}, \dots)_{\zeta < \zeta_f}$ , where  $w[f] = \{\eta(f, \zeta) : \zeta < \zeta_f\}$ ; and  $f \in \mathcal{F} \Rightarrow (\exists W \in \mathbf{W})[w[f] = \{\eta \upharpoonright \alpha : \eta \in W\}]$ , see clause (e) below;

- (d): for each  $\bar{b} \in {}^{\kappa>}M$ , an expansion  $M_{\bar{b}}$  of  $(M, \bar{b})$  to a model of  $T^*[\bar{b}, M]$ , (see above in Definition 2.3; so  $M_{\bar{b}}$  has Skolem functions and it witnesses  $\kappa$ -resplendency for this sequence in  $M$ );
- (e):  $\mathbf{W} = \mathbf{W}_{\mathbf{m}} \subseteq \mathbf{W}_{\alpha}$  which is  $\alpha$ -invariant and hereditary;
- (f): for  $W \in \mathbf{W}$ ,  $N_W$  which is the submodel of  $M$  with universe

$$\{f(\dots, \eta_{\zeta}, \dots)_{\zeta < \zeta_f} : f \in \mathcal{F}, f(\dots, \eta_{\zeta}, \dots)_{\zeta < \zeta_f} \text{ well defined, and } \eta_{\zeta} \in W \text{ for every } \zeta\},$$

- (g): a function  $\mathbf{f} = \mathbf{f}_{\mathbf{m}}$ ,

such that  $\mathbf{m}$  satisfies the following:

- (A):  $M$  is a model of  $T$ ,
- (B): [witness for  $\kappa < \kappa(T)$ ]: for our fixed sequence of first order formulas  $\langle \varphi_{\zeta}(x, y) : \zeta < \kappa \rangle$  from  $\mathbb{L}(\tau_T)$  depending neither on  $\alpha$  nor on  $\mathbf{m}$  we have  $f_{\rho, \zeta}^* \in \mathcal{F}$  for  $\zeta \leq \kappa$ ,  $\rho \in {}^{\alpha}\mu$  (we also call them  $f_{\rho, \zeta}^{\mathbf{m}}$ ) such that:
  - (i):  $f_{\rho, \zeta}^*$  is a one place function, with  $\zeta_{f_{\rho, \zeta}^*}, \eta_0^{f_{\rho, \zeta}^*}$  from clause (c) being  $1, \rho$  respectively.
  - (ii):  $f_{\rho_1, \zeta}^*(\nu_1) = f_{\rho_2, \zeta}^*(\nu_2)$  if  $\nu_1 \upharpoonright \zeta = \nu_2 \upharpoonright \zeta$  and they are well defined, i.e.  $\rho_{\ell} \triangleleft \nu_{\ell} \in {}^{\kappa}\mu$ ,
  - (iii): if  $\rho_{\ell} \in {}^{\alpha}\mu$ ,  $\nu_{\ell} \in I_{\rho_{\ell}}^{\alpha}$  for  $\ell = 1, 2$  and  $\zeta < \kappa$  then:

$$M \models \varphi_{\zeta} [f_{\rho_1, \kappa}^*(\nu_1), f_{\rho_2, \zeta+1}^*(\nu_2)] \quad \text{iff} \quad [\nu_1 \upharpoonright (\zeta+1) = \nu_2 \upharpoonright (\zeta+1)],$$

- (C):  $N_W \prec M$ , for  $W \in \mathbf{W}$ ,
- (D): [ $\mathbf{f} = \mathbf{f}_{\mathbf{m}}$  witness an amount of resplendency]
  - (a): the domain of  $\mathbf{f}$  is a subset of

$$\mathbb{F}_{\mathbf{m}} =: \{\bar{f} : \bar{f} = \langle f_{\varepsilon} : \varepsilon < \varepsilon_{\bar{f}} \rangle, \varepsilon_{\bar{f}} < \kappa, f_{\varepsilon} \in \mathcal{F}, \text{ and } \zeta_{f_{\varepsilon}} \text{ does not depend on } \varepsilon, \text{ call it } \zeta_{\bar{f}} \text{ and for } \zeta < \zeta_{\bar{f}} \text{ the sequence } \eta(f_{\varepsilon}, \zeta) \text{ does not depend on } \varepsilon, \text{ call it } \eta(\bar{f}, \zeta)\},$$

( $\beta$ ): for  $\bar{f} \in \text{Dom}(\mathbf{f})$ ,  $\mathbf{f}(\bar{f})$  is a function with domain

$$\{\sigma(\bar{x}) : \sigma(\bar{x}) \text{ is a } \tau[T, \varepsilon_{\bar{f}}]\text{-term, and } \bar{x} = \langle x_\xi : \xi \in u \rangle \text{ for some finite subset } u = u_\sigma \text{ of } \varepsilon_{\bar{f}}\}$$

and if  $\sigma(\bar{x}) \in \text{Dom}(\mathbf{f}(\bar{f}))$  then

$$\mathbf{f}(\bar{f})(\sigma(\bar{x})) \in \mathcal{F}[\bar{f}] := \{f \in \mathcal{F} : \zeta_f = \zeta_{\bar{f}} \text{ \& } (\forall \zeta < \zeta_f)(\eta(f, \zeta) = \eta(\bar{f}, \zeta))\},$$

- ( $\gamma$ ):
- if  $\bar{f} \in \text{Dom}(\mathbf{f})$  and  $\bar{b} = \langle f_\varepsilon(\dots, \nu_{\eta(\bar{f}, \zeta)}, \dots)_{\zeta < \zeta_{\bar{f}}} \rangle$  then the universe of  $M_{\bar{b}}$  is  $\{f((\dots, \nu_{\eta(\bar{f}, \zeta)}, \dots)_{\zeta < \zeta_{\bar{f}}}) : f \in \mathcal{F}[\bar{f}]\}$
  - if  $(\mathbf{f}(\bar{f}))(\sigma(\bar{x})) = f^* \in \mathcal{F}$ ,  $W \in \mathbf{W}$ ,  $\nu_\zeta \in W$  and  $\nu_\zeta \upharpoonright \alpha = \eta(\bar{f}, \zeta)$  for  $\zeta < \zeta_f$ , and  $\bar{x} = \langle x_\xi : \xi \in u \rangle$ , and  $\bar{b} = \bar{f}(\bar{v}) = \langle f_\varepsilon(\bar{v}) : \varepsilon < \varepsilon_{\bar{f}} \rangle$ , then

$$\sigma^{M_{\bar{b}}}(\langle f_\varepsilon(\dots, \nu_\zeta, \dots)_{\zeta < \zeta_f} : \xi \in u \rangle) = f^*(\dots, \nu_\zeta, \dots)_{\zeta < \zeta_f}.$$

[explaining ( $\gamma$ ): we may consider  $\bar{b} \in N_{W_1} \cap N_{W_2}$ , and we better have that the witnesses for resplendency demands, specialized to  $\bar{b}$ , in  $N_{W_1}$  and in  $N_{W_2}$  are compatible so that in the end resplendency holds].

However, we shall not get far without at least more closure and coherence of the parts of  $\mathbf{m}$ .

**Definition 2.6.** (1) An approximation  $\mathbf{m}$  is called full if  $\mathbf{W}_{\mathbf{m}} = \mathbf{W}_{\alpha(\mathbf{m})}$ , and is called semi-full if  $\mathbf{W}_{<\alpha(\mathbf{m})} \subseteq \mathbf{W}_{\mathbf{m}} \subseteq \mathbf{W}_{\alpha(\mathbf{m})}$  and is called almost full if it is semi full when  $\alpha$  is limit ordinal and full when  $\alpha$  is a non-limit ordinal.  
 (2) An approximation  $\mathbf{m}$  is  $\beta$ -resplendent if  $\beta \leq \alpha_{\mathbf{m}}$  and

$$\begin{aligned} &\text{if } W \in \mathbf{W}_\beta \cap \mathbf{W}_{\mathbf{m}} \text{ and } \bar{f} \in \mathbb{F}_{\mathbf{m}}, \text{ and} \\ &\quad \{\eta(\bar{f}, \zeta) : \zeta < \zeta_{\bar{f}}\} \subseteq \{\nu \upharpoonright \alpha : \nu \in W\}, \\ &\text{then } f \in \text{Dom}(\mathbf{f}_{\mathbf{m}}). \end{aligned}$$

- (3) In part (2), if we omit  $\beta$ , we mean  $\beta = \alpha_{\mathbf{m}}$ , and “ $< \beta^*$ ” means for every  $\beta < \beta^*$ .  
 (4) An approximation  $\mathbf{m}$  is called term closed if:

(E): Closure under terms of  $\tau$ :

Assume that  $u \subseteq {}^\alpha \mu$ ,  $|u| < \kappa$ , and for some  $W \in \mathbf{W}_{\mathbf{m}}$ ,  $u \subseteq \{\eta \upharpoonright \alpha : \alpha \in W\}$ , and  $\langle \eta_\zeta : \zeta < \zeta^* \rangle$  lists  $u$  with no repetitions and  $f_\ell \in \mathcal{F}_{\mathbf{m}}$ ,  $\ell < n$ , satisfies  $\{\eta(f_\ell, \zeta) : \zeta < \zeta_{f_\ell}\} \subseteq u$ ,  $\sigma$  is an  $n$ -place  $\tau(T)$ -term so  $\sigma = \sigma(x_0, \dots, x_{n-1})$ . Then for some  $f \in \mathcal{F}_{\mathbf{m}}$  satisfying  $\zeta_f = \zeta^*$ ,  $\eta(f, \zeta) = \eta_\zeta$ , for any choice of  $\langle \nu_\eta : \eta \in u \rangle$  such that  $\eta \triangleleft \nu_\eta \in {}^\kappa \mu$  for  $\eta \in u$ , and  $\{\nu_\eta : \eta \in u\} \subseteq W' \in \mathbf{W}$  for some  $W'$  we have

$$f_{\mathbf{m}}(\dots, \nu_\eta, \dots)_{\eta \in w[f]} = \sigma(\dots, f_\ell^{\mathbf{m}}(\dots, \nu_\eta, \dots)_{\eta \in w[f_\ell]}, \dots)_{\ell < n}$$

(this clause may be empty, but it helps to understand clause (F); note that it is not covered by 2.5(D) as the functions are not necessarily with the same domain, hence this says something even for  $\sigma$  the identity: so this implies that in clause (f) of Definition 2.5 we can demand  $\{\eta_{\mathbf{m}}(f, \zeta) : \zeta < \zeta_f\} = W$ ).

(F): Closure under terms of  $\tau(M_{\bar{b}})$ :

Assume that  $u \subseteq {}^\alpha \mu$ ,  $|u| < \kappa$ , and  $\langle \eta_\zeta : \zeta < \zeta^* \rangle$  lists  $u$  with no repetitions, and for some  $W \in \mathbf{W}_{\mathbf{m}}$ ,  $u \subseteq \{\eta \upharpoonright \alpha : \eta \in W\}$ . If  $n < \omega$

and  $f^\ell \in \mathcal{F}_m$  for  $\ell < n$ ,  $\bar{f} = \langle f_\varepsilon : \varepsilon < \varepsilon(*) \rangle \in \text{Dom}(\mathbf{f}_m)$ , and

$$\begin{aligned} \eta(f_\varepsilon, \zeta) &\in u && \text{for } \zeta < \zeta_{f_\varepsilon}, \text{ and} \\ \eta(f^\ell, \zeta) &\in u && \text{for } \zeta < \zeta_{f^\ell}, \text{ and} \\ b_\varepsilon &= f_\varepsilon(\dots, \nu_{\eta(f_\varepsilon, \zeta)}, \dots)_\zeta && \text{for } \varepsilon < \varepsilon(*), \end{aligned}$$

$\bar{b} = \langle b_\varepsilon : \varepsilon < \varepsilon(*) \rangle$  and  $\sigma(x_0, \dots, x_{n-1})$  is a  $\tau(M_{\bar{b}})$ -term,

then for some  $f \in \mathcal{F}_m$  we have  $w[f] = u$  and:

if  $\nu_\eta \in I_\eta^\alpha$  for  $\eta \in u$  and  $\{\nu_\eta : \eta \in u\} \in \mathbf{W}_m$ , then

$$f_m(\dots, \nu_\eta, \dots)_{\eta \in u} = \sigma^{M_{\bar{b}}}(\dots, f_m^\ell(\dots, \nu_{\eta(f^\ell, \zeta)}, \dots)_{\zeta < \zeta(f^\ell)}, \dots)_{\ell < n}.$$

**Observation 2.7.** In Definition 2.6(4) in clauses (E), (F) it suffice to restrict ourselves to the case  $n = 1$  and  $\sigma$  is the identity.

Proof: By 2.5(D) $\gamma$ ).

Of course some form of indiscernibility will be needed.

**Definition 2.8.** (1) Let  $\mathbb{E}$  be the family of equivalence relations  $\mathbf{E}$  on

$$\{\bar{\nu} \in {}^\kappa > (\kappa \mu) : \bar{\nu} \text{ without repetitions}\},$$

or a subset of it, such that

$$\bar{\nu}^1 \mathbf{E} \bar{\nu}^2 \Rightarrow \text{lg}(\bar{\nu}^1) = \text{lg}(\bar{\nu}^2).$$

(2) Let  $\mathbb{E}_\alpha$  be the family of  $\mathbf{E} \in \mathbb{E}$  such that

$$\bar{\nu} \in \text{Dom}(\mathbf{E}) \Rightarrow \langle \nu_\zeta \restriction \alpha : \zeta < \text{lg}(\bar{\nu}) \rangle \text{ is without repetitions.}$$

(3) Let  $\mathbf{E}_\alpha^0 \in \mathbb{E}_\alpha$  be the following equivalence relation:

$$\begin{aligned} \bar{\nu}^1 \mathbf{E}_\alpha^0 \bar{\nu}^2 &\text{ iff } && \text{for some } \zeta < \kappa \text{ we have} \\ &(i) && \bar{\nu}^1, \bar{\nu}^2 \in {}^\zeta (\kappa \mu), \\ &(ii) && \bar{\nu}_\varepsilon^1 \restriction \alpha = \bar{\nu}_\varepsilon^2 \restriction \alpha \text{ for } \varepsilon < \zeta, \\ &(iii) && \langle \bar{\nu}_\varepsilon^1 \restriction \alpha : \varepsilon < \zeta \rangle \text{ is with no repetitions,} \\ &(iv) && \text{the set } \{\varepsilon < \zeta : \bar{\nu}_\varepsilon^1 \neq \bar{\nu}_\varepsilon^2\} \text{ is finite.} \end{aligned}$$

(3A) We say that  $(\bar{\nu}^1, \bar{\nu}^2)$  are immediate neighbours if  $\text{lg}(\bar{\nu}^1) = \text{lg}(\bar{\nu}^2)$ , and for some  $\xi < \text{lg}(\bar{\nu}^1)$  we have  $(\forall \varepsilon < \zeta)(\varepsilon \neq \xi \Leftrightarrow \bar{\nu}_\varepsilon^1 = \bar{\nu}_\varepsilon^2)$ ; so the difference with (3) is that “finite” is replaced by “a singleton”.

(4) Let  $\mathbf{E}_{<\alpha}^0$  be defined like  $\mathbf{E}_\alpha^0$  strengthening clause (iii) to

(iii)<sup>+</sup>: for some  $\beta < \alpha$ , the sequence  $\langle \bar{\nu}_\varepsilon^\ell \restriction \beta : \varepsilon < \zeta \rangle$  is with no repetitions.

(5) For  $\alpha < \kappa$  and  $\mathbf{W} \subseteq \mathbf{W}_\alpha$  let

$$\begin{aligned} \text{seq}_\alpha(\mathbf{W}) &= \{\bar{\nu} : \bar{\nu} \in {}^\kappa > (\kappa \mu) \text{ is with no repetitions,} \\ &\text{and for some } W \in \mathbf{W} \text{ we have} \\ &\{\nu_\xi : \xi < \text{lg}(\bar{\nu})\} \subseteq W, \text{ and hence} \\ &\langle \nu_\zeta \restriction \alpha : \zeta < \text{lg}(\bar{\nu}) \rangle \text{ is with no repetitions}\}. \end{aligned}$$

(6) We define  $\mathbf{E}_\alpha^1$  as we define  $\mathbf{E}_\alpha^0$  in part (3) above, omitting clause (iv). We define  $\mathbf{E}_{<\alpha}^1$  paralelly as in part (4).

REMARK: The reader may concentrate on  $\mathbf{E}_\alpha^0$ , so the “weakly” version below.

**Definition 2.9.** (1) An approximation  $\mathbf{m}$  is called  $\mathbf{E}$ -indiscernible if

(a):  $\mathbf{E} \in \mathbb{E}_{\alpha(\mathbf{m})}$  refine  $\mathbf{E}_{\alpha(\mathbf{m})}^1$ ,

- (b): if  $\bar{\nu}^1, \bar{\nu}^2 \in \text{seq}_{\alpha(\mathbf{m})}(\mathbf{W}_{\mathbf{m}})$  and  $\bar{\nu}^1 \mathbf{E} \bar{\nu}^2$ , then there is  $g$  (in fact, a unique  $g = g_{\bar{\nu}^1, \bar{\nu}^2}^{\mathbf{m}}$ ) such that
- ( $\alpha$ ):  $g$  is an  $(M_{\mathbf{m}}, M_{\mathbf{m}})$ -elementary mapping,
  - ( $\beta$ ):  $\text{Dom}(g) = \{f(\langle \nu_{h(\zeta)}^1 : \zeta < \zeta_f \rangle) : f \in \mathcal{F}_{\mathbf{m}} \text{ and } h \text{ is a one-to-one function from } \zeta_f \text{ into } \text{lg}(\bar{\nu}^\ell) \text{ such that } \eta(f, \zeta) \triangleleft \nu_\zeta^1\}$ ,
  - ( $\gamma$ ):  $g(f(\langle \nu_{h(\zeta)}^1 : \zeta < \zeta_f \rangle)) = f(\langle \nu_{h(\zeta)}^2 : \zeta < \zeta_f \rangle)$  for  $f, h$  as above;
- (c): Assume  $\bar{\nu}^1, \bar{\nu}^2 \in \text{seq}_{\alpha(\mathbf{m})}(\mathbf{W}_{\mathbf{m}})$ ,  $\bar{f}^1, \bar{f}^2 \in \text{Dom}(\mathbf{f}_{\mathbf{m}})$ ,  $\zeta^* = \zeta_{\bar{f}^1} = \zeta_{\bar{f}^2}$ , and for some one-to-one function  $h$  from  $\zeta^*$  to  $\text{lg}(\bar{\nu}^\ell)$  we have  $\eta(\bar{f}^\ell, \zeta) = \nu_{h(\zeta)}^{\mathbf{m}} \upharpoonright \alpha$  for  $\ell, m = 1, 2$ , and  $\bar{\nu}^1 \mathbf{E} \bar{\nu}^2$ . Let
- $$\bar{b}^\ell = \langle f_\varepsilon^\ell(\langle \nu_{h(\zeta)}^\ell : \zeta < \zeta^* \rangle) : \varepsilon < \text{lg}(\bar{f}^\ell) \rangle.$$

Then there is  $g$  such that

- ( $\alpha$ ):  $g$  is an  $(M_{\bar{b}^1}^{\mathbf{m}}, M_{\bar{b}^2}^{\mathbf{m}})$ -elementary mapping,
  - ( $\beta$ ):  $g = g_{\bar{\nu}^1, \bar{\nu}^2}^{\mathbf{m}}$  from clause (b) above.
- (2) An approximation  $\mathbf{m}$  is strongly indiscernible if it is  $\mathbf{E}_{\alpha(\mathbf{m})}^1$ -indiscernible.
- (3) (a) An approximation  $\mathbf{m}$  is weakly indiscernible when it is  $\mathbf{E}_{\alpha(\mathbf{m})}^0$ -indiscernibility.
- (b) An approximation  $\mathbf{m}$  is weakly/strongly nice if it is term closed and weakly/strongly indiscernible.
- (c) An approximation  $\mathbf{m}$  weakly/strongly good if it is weakly/strongly nice and is almost full.
- (d) An approximation  $\mathbf{m}$  is weakly/strongly excellent if it is weakly/strongly good, and is resplendent, see Definition 2.6(2), (3).

**Discussion 2.10.** Why do we have the weak and strong version?

In the proof of the main subclaim 2.19 below the proof for the weak version is easier but we get from it a weaker conclusion:  $\geq \lambda^+$  non-isomorphic  $\kappa$ -resplendent of cardinality  $\lambda = \lambda^\kappa$ , whereas from the strong version we would get  $2^\lambda$ . But see §3.

**Claim 2.11.** Let  $\mathbf{m}$  be an approximation.

- (1) In the definition of “ $\mathbf{m}$  is  $\mathbf{E}_\alpha^0$ -indiscernible”, it is enough to deal with immediate  $\mathbf{E}_\alpha^0$ -neighbors (see Definition 2.8(3)).
- (2) If  $\mathbf{m}$  is weakly/strongly excellent then  $\mathbf{m}$  is weakly/strongly good.
- (3) If  $\mathbf{m}$  is weakly/strongly good then  $\mathbf{m}$  is weakly/strongly nice.
- (4) If  $\alpha_{\mathbf{m}} = 0$ ,  $\mathbf{E} \in \mathbb{E}_{\mathbf{m}}$  then  $\mathbf{m}$  is  $\mathbf{E}$ -indiscernible if and only if  $\mathbf{m}$  is strongly indiscernible.

**Definition 2.12.** (1) For approximations  $\mathbf{m}_1, \mathbf{m}_2$  let “ $\mathbf{m}_1 \leq_{\mathbf{h}} \mathbf{m}_2$ ” or “ $\mathbf{m}_1 \leq \mathbf{m}_2$  as witnessed by  $\mathbf{h}$ ” mean that:

- (a):  $\alpha(\mathbf{m}_1) \leq \alpha(\mathbf{m}_2)$ ,
- (b):  $\mathbf{W}_{\mathbf{m}_1} \subseteq \mathbf{W}_{\mathbf{m}_2}$ ,
- (c):  $h$  is a partial function from  $\mathcal{F}_{\mathbf{m}_2}$  into  $\mathcal{F}_{\mathbf{m}_1}$ ,
- (d): if  $\mathbf{h}(f_2) = f_1$  then they have the same arity (i.e.,  $\zeta_{f_1}^{\mathbf{m}_1} = \zeta_{f_2}^{\mathbf{m}_2}$ ) and
$$\zeta < \zeta_{f_1}^{\mathbf{m}_1} \Rightarrow \eta_{\mathbf{m}_1}(f_1, \zeta) = \eta_{\mathbf{m}_2}(f_2, \zeta) \upharpoonright \alpha(\mathbf{m}_1),$$
- (e): if  $f_1 \in \mathcal{F}_{\mathbf{m}_1}$  and  $W \in \mathbf{W}_{\mathbf{m}_1}$  and
$$\{\nu \upharpoonright \alpha(\mathbf{m}_1) : \nu \in W\} = \{\eta_{\mathbf{m}_1}(f_1, \zeta) : \zeta < \zeta_{f_1}^{\mathbf{m}_1}\},$$
then there is one and only one  $f_2 \in \mathcal{F}_{\mathbf{m}_2}$  satisfying
$$\mathbf{h}(f_2) = f_1 \quad \text{and} \quad \{\eta_{\mathbf{m}_1}(f_2, \zeta) : \zeta < \zeta_{f_2}^{\mathbf{m}_1}\} = \{\nu \upharpoonright \alpha(\mathbf{m}_2) : \nu \in W\},$$

(f): for  $W \in \mathbf{W}_{\mathbf{m}_1}$ , the mapping  $g_{\mathbf{m}_1}^{\mathbf{m}_2}[W, \mathbf{h}]$  defined below is an elementary embedding from  $N_W^{\mathbf{m}_1}$  into  $N_W^{\mathbf{m}_2}$ , where:

(\*) : if  $f_1 \in \mathcal{F}_{\mathbf{m}_1}$ ,  $f_2 \in \mathcal{F}_{\mathbf{m}_2}$  are as in clause (e) (so  $h(f_2) = f_1$ ), and

$$a = f_1^{\mathbf{m}_1}(\dots, \nu_\zeta, \dots)_{\zeta < \zeta_{f_1}}, \quad \text{and} \quad \{\nu_\zeta : \zeta < \zeta_f^{\mathbf{m}_1}\} \subseteq W$$

(so  $a \in N_W^{\mathbf{m}_1}$ ), then  $(g_{\mathbf{m}_1}^{\mathbf{m}_2}[W, \mathbf{h}])(a) = f_2^{\mathbf{m}_2}(\dots, \nu_\zeta, \dots)_{\zeta < \zeta_{f_2}}$ ,

(g): if  $\bar{f}^1 = \langle f_\xi^1 : \xi < \varepsilon \rangle \in \text{Dom}(\mathbf{f}_{\mathbf{m}_1})$  and  $\eta_{\mathbf{m}_1}(\bar{f}^1, \zeta) \leq \eta_\zeta \in {}^{\alpha(\mathbf{m}_2)}\mu$  for  $\zeta < \zeta_{\bar{f}^1}^{\mathbf{m}_1}$ ,  $\bar{f}^2 = \langle f_\xi^2 : \xi < \varepsilon \rangle \in {}^\varepsilon(\mathcal{F}_{\mathbf{m}_2})$ , and  $\zeta_{\bar{f}^2}^{\mathbf{m}_2} = \zeta_{\bar{f}^1}^{\mathbf{m}_1}$ , and  $\xi < \varepsilon \& \zeta < \zeta_{\bar{f}^1} \Rightarrow \eta(f_\xi^2, \zeta) = \eta_\zeta$ , &  $h(f_\xi^2) = f_\xi^1$ , then

(α):  $\bar{f}^2 \in \text{Dom}(\mathbf{f}_{\mathbf{m}_2})$ ,

(β):  $h((\mathbf{f}_{\mathbf{m}_2}(\bar{f}^2))(\sigma(\langle x_\xi : \xi \in u \rangle))) = (\mathbf{f}_{\mathbf{m}_1}(\bar{f}^1))(\sigma(\langle x_\xi : \xi \in u \rangle))$ ,  
when  $u$  is a finite subset of  $\varepsilon$

(γ): assume  $\nu_\zeta \in I_{\eta_\zeta}$  for  $\zeta < \zeta_{\bar{f}^1}^{\mathbf{m}_1}$ , and  $W = \{\nu_\zeta : \zeta < \zeta_{\bar{f}^1}^{\mathbf{m}_1}\}$ ,  
 $\bar{b}^\ell = \langle f_\xi^\ell(\dots, \nu_\zeta, \dots)_{\zeta : \xi < \varepsilon} \rangle$ , then the mapping  $g_{\mathbf{m}_1}^{\mathbf{m}_2}[W, h]$  (see clause (f) above) is an isomorphism from  $M_{\bar{b}^1}^{\mathbf{m}_1} \upharpoonright |N_W^{\mathbf{m}_1}|$  onto  $M_{\bar{b}^2}^{\mathbf{m}_2} \upharpoonright |N_W^{\mathbf{m}_2}|$ .

(2) We say that  $\langle \mathbf{m}_\beta, \mathbf{h}_\gamma^\beta : \beta < \alpha, \gamma \leq \beta \rangle$  is an inverse system of approximations if

(a):  $\mathbf{m}_\beta$  is a  $\beta$ -approximation (for  $\beta < \alpha$ ),

(b):  $\mathbf{m}_\gamma \leq_{\mathbf{h}_\gamma^\beta} \mathbf{m}_\beta$  for  $\gamma \leq \beta$ ,

(c):  $\mathbf{h}_\beta^\beta$  is the identity,

(d): if  $\beta_0 < \beta_1 < \beta_2 < \alpha$  then  $\mathbf{h}_{\beta_0}^{\beta_2} = \mathbf{h}_{\beta_0}^{\beta_1} \circ \mathbf{h}_{\beta_1}^{\beta_2}$ .

(3) We say that an inverse system of approximations  $\langle \mathbf{m}_\beta, \mathbf{h}_\gamma^\beta : \beta < \alpha, \gamma \leq \beta \rangle$  is continuous at  $\delta$  if:

(a):  $\delta < \alpha$  is a limit ordinal,

(b):  $\mathbf{W}_{\mathbf{m}_\delta} = \bigcup \{\mathbf{W}_{\mathbf{m}_\beta} : \beta < \delta\}$ ,

(c):  $\mathcal{F}_{\mathbf{m}_\delta} = \bigcup \{\text{Dom}(\mathbf{h}_\beta^\delta) : \beta < \delta\}$ ,

(d):  $\text{Dom}(\mathbf{f}_{\mathbf{m}_\delta}) = \{\bar{f}^2 : \text{for some } \beta < \delta \text{ and } \bar{f}^1 \in \text{Dom}(\mathbf{f}_{\mathbf{m}_1}) \text{ of length } \ell g(\bar{f}^2) \text{ we have } \mathbf{h}_\beta^\delta(f_\xi^2) = f_\xi^1 \text{ for } \xi < \ell g(\bar{f}^2)\}$ .

Discussion: Having chosen above our order, when can we get the appropriate indiscernibility? As we are using finitary partition theorem (with finitely many colours), we cannot make the type of candidates for  $\bar{b}$  fixed. However we may have a priori enough indiscernibility to fix the type of enough  $\bar{b}'$ 's and then use the indiscernible existence to uniforming the related  $M_{\bar{b}}$ 's.

**Claim 2.13.** *There is an excellent 0-approximation.*

Proof: Recall that the sequence  $\langle \varphi_\alpha(x, y) : \alpha < \kappa \rangle$  exemplifies  $\kappa < \kappa(T)$ , see 2.1 above. Hence by clause (b) of [Sh:E59, 1.10(3)], we can find a template  $\Phi$  proper for the tree  $I_\square$ , i.e.,  $\kappa \geq \mu$ , with skeleton  $\langle a_\eta : \eta \in \kappa \geq \mu \rangle$  such that for  $\nu \in \kappa \mu$  and  $\rho \in {}^{\alpha+1}\mu$  we have

$$\text{EM}(\kappa \geq \mu, \Phi) \models \varphi_\alpha(a_\nu, a_\rho) \quad \text{iff} \quad \rho \triangleleft \nu.$$

Without loss of generality, for some unary function symbols  $F_\varepsilon^* \in \tau(\Phi)$ , we have  $\text{EM}(\kappa \geq \mu, \Phi) \models "F_\varepsilon(a_\eta) = a_{\eta \upharpoonright \varepsilon}"$  for  $\eta \in \kappa \mu$ . Now, by induction on  $\varepsilon < \kappa$  we choose  $\Phi_\varepsilon$  such that

- (a):  $\Phi_\varepsilon$  is a template proper for  $\kappa^\geq \mu$  which is nice (see [Sh:E59, 1.7] + [Sh:E59, 1.8(2)]),
- (b):  $\tau(\Phi_\varepsilon)$  has cardinality  $\leq \theta$  (see Definition 2.3),
- (c):  $\Phi_0 = \Phi$ ,
- (d): the sequence  $\langle \Phi_\varepsilon : \varepsilon < \kappa \rangle$  is increasing with  $\varepsilon$ , that is,

$$\zeta < \varepsilon \Rightarrow \tau(\Phi_\zeta) \subseteq \tau(\Phi_\varepsilon) \text{ and } \text{EM}^1(\kappa^\geq \mu, \Phi_\zeta) \prec \text{EM}^1(\kappa^\geq \mu, \Phi_\varepsilon),$$

- (e): the sequence  $\langle \Phi_\varepsilon : \varepsilon < \kappa \rangle$  is continuous, i.e., if  $\varepsilon$  is a limit ordinal then  $\tau(\Phi_\varepsilon) = \bigcup_{\zeta < \varepsilon} \tau(\Phi_\zeta)$ ,
- (f): if  $\bar{\sigma} = \langle \sigma_i(x) : i < i^* \rangle$  is a sequence of length  $< \kappa$  of unary terms in  $\tau(\Phi_\varepsilon)$ , and  $M^{\varepsilon+1} = \text{EM}^1(\kappa^\geq \mu, \Phi_{\varepsilon+1})$ , and for  $\nu \in {}^\kappa \mu$  we define  $\bar{b} = \bar{b}_{\bar{\sigma}, \nu}$  as

$$\langle \sigma_i^{M^{\varepsilon+1}}(a_\nu) : i < i^* \rangle \in {}^{i^*}(\text{EM}^1(\{\nu\}, \Phi_{\varepsilon+1})),$$

then we can interpret a model  $M_b^{\varepsilon+1}$  of  $T^*[\bar{b}, M^{\varepsilon+1} \upharpoonright \tau_T]$  in  $M^{\varepsilon+1}$ , which means

- ( $\alpha$ ): if  $R \in \tau_T[\bar{b}, M^{\varepsilon+1} \upharpoonright \tau(T)] \setminus \tau_T$  is a  $k$ -place predicate, then there is a  $(k+1)$ -place predicate  $R_* \in \tau(\Phi_{\varepsilon+1}) \setminus \tau(\Phi_\varepsilon)$  such that

$$M_b^{\varepsilon+1} \models R[c_0, \dots, c_{k-1}] \quad \text{iff} \quad M^{\varepsilon+1} \models R_*[c_0, \dots, c_{k-1}, a_\nu],$$

- ( $\beta$ ): if  $F \in \tau_T[\bar{b}, M^{\varepsilon+1} \upharpoonright \tau(T)] \setminus \tau_T$  is a  $k$ -place function symbol, then there is a  $(k+1)$ -place function symbol  $F_* \in \tau(\Phi_{\varepsilon+1}) \setminus \tau(\Phi_\varepsilon)$  such that

$$M_b^{\varepsilon+1} \models "F[c_0, \dots, c_{k-1}] = c" \quad \text{iff} \quad M^{\varepsilon+1} \models "F_*[c_0, \dots, c_{k-1}, a_\nu] = c".$$

Let us carry out the induction; note that there is a redundancy in our contraction: each relevant  $\bar{b}$  is taken care of in the  $\varepsilon$ -th stage for every  $\varepsilon < \kappa$  large enough, independently, for the different  $\varepsilon$ -s.

For  $\varepsilon = 0$ :

Let  $\Phi_0 = \Phi$ .

For a limit  $\varepsilon$ :

Let  $\Phi_\varepsilon$  be the direct limit of  $\langle \Phi_\zeta : \zeta < \varepsilon \rangle$ .

For  $\varepsilon = \zeta + 1$ :

Let the family of sequences of the form  $\bar{\sigma} = \langle \sigma_i(x) : i < i^* \rangle$ , where  $\sigma_i(x)$  is a unary term in  $\tau(\Phi_\zeta)$ ,  $i^* < \kappa$ , be listed as  $\langle \bar{\sigma}^\gamma(x) : \gamma < \theta \rangle$ , with  $\bar{\sigma}^\gamma(x) = \langle \sigma_i^\gamma(x) : i < i_\gamma^* \rangle$ . Let  $M_\varepsilon^*$  be a  $\theta^+$ -resplendent (hence strongly  $\theta^+$ -homogeneous and  $\kappa$ -resplendent) elementary extension of  $\text{EM}^1(\kappa^\geq \mu, \Phi_\zeta)$ , and let  $M_\varepsilon = M_\varepsilon^* \upharpoonright \tau_T$ , and choose  $\nu^* \in {}^\kappa \mu$ . For each  $\gamma < \theta$  let  $\bar{b}_{\nu^*}^\gamma =: \langle \sigma_i^\gamma(a_{\nu^*}) : i < i_\gamma^* \rangle$ . Now,  $(M_\varepsilon, \bar{b}_{\nu^*}^\gamma)$  can be expanded to a model  $M_{\bar{b}_{\nu^*}^\gamma}^\zeta$  of  $T^*[\bar{b}_{\nu^*}^\gamma, M_\varepsilon]$ , and let

$$\tau(T^*[\bar{b}, M_\varepsilon]) \setminus \tau_T = \{R_{j,n}^{\varepsilon, \gamma} : j < \theta, n < \omega\} \cup \{F_{j,n}^{\varepsilon, \gamma} : j < \theta, n < \omega\},$$

where  $R_{j,n}^{\varepsilon, \gamma}$  is an  $n$ -place predicate and  $F_{j,n}^{\varepsilon, \gamma}$  is an  $n$ -place function symbol. Next we shall define an expansion  $M_\varepsilon^+$  of  $M_\varepsilon^*$ . Its vocabulary is

$$\tau(\Phi_\zeta) \cup \{R_{\varepsilon, \gamma, j, n}, F_{\varepsilon, \gamma, j, n} : j < \theta, n < \omega\},$$

where  $R_{\varepsilon, \gamma, j, n}$  is an  $(n+1)$ -place predicate,  $F_{\varepsilon, \gamma, j, n}$  is an  $(n+1)$ -place function symbol, and no one of them is in  $\tau(\Phi_\zeta)$  (and there are no repetitions in their list).



Almost lastly, for  $\nu \in {}^\kappa\mu$  let  $g_\nu$  be an automorphism of  $M_\varepsilon$  mapping  $EM^1(\{\nu^*\}, \Phi_\zeta)$  onto  $EM^1(\{\nu\}, \Phi_\zeta)$ ; moreover such that for any  $\tau(\Phi_\zeta)$ -term  $\sigma(x)$  we have  $g_\nu(\sigma(a_{\nu^*})) = \sigma(a_\nu)$  (hence  $\xi < \kappa \Rightarrow g_\nu(a_{\nu^* \upharpoonright \xi}) = a_{\nu \upharpoonright \xi}$  using  $\sigma(x) = F_\xi^*(x)$ ).

Now we actually define  $M_\varepsilon^+$  expanding  $M_\varepsilon^+ M_\varepsilon^*$ :

$$R_{\varepsilon, \gamma, j, n}^{M_\varepsilon^+} = \{(g_\nu(c_0), g_\nu(c_1), \dots, g_\nu(c_{n-1}), g_\nu(a_{\nu^*})) : \\ M_{\bar{b}_{\nu^*}}^\zeta \models R_{j, n}^{\varepsilon, \gamma}(c_0, \dots, c_{n-1})\},$$

$F_{\varepsilon, \gamma, j, n}^{M_\varepsilon^+}$  is an  $(n+1)$ -place function such that

$$M_{\bar{b}_{\nu^*}}^\zeta \models F_{j, n}^{\varepsilon, \gamma}(c_0, \dots, c_{n-1}) = c \quad \text{implies}$$

$$F_{\varepsilon, \gamma, j, n}^{M_\varepsilon^+}(g_\nu(c_0), \dots, g_\nu(c_{n-1}), a_\nu) = g_\nu(c).$$

We further expand  $M_\varepsilon^+$  to  $M_\varepsilon^{++}$ , with vocabulary of cardinality  $\leq \theta$  and with Skolem functions.

Now we apply “ $\kappa \geq \mu$  has the Ramsey property” (see [Sh:E59, 1.14(4)] see “even” there, [Sh:E59, 1.18]) to get  $\Phi_\varepsilon = \Phi_{\zeta+1}$ ,  $\tau(\Phi_\varepsilon) = \tau(M_\varepsilon^{++})$ , such that for every  $n < \omega$ ,  $\nu_1, \dots, \nu_n \in {}^\kappa\mu$ , and first order formula  $\varphi(x_1, \dots, x_n) \in \mathbb{L}(\tau(\Phi_\varepsilon))$ , for some  $\eta_1, \dots, \eta_n \in {}^\kappa\mu$  we have

$$(\alpha): M_\varepsilon^{++} \models \varphi[a_{\eta_1}, \dots, a_{\eta_n}] \text{ iff } EM^1(\kappa \geq \mu, \Phi_\varepsilon) \models \varphi[a_{\nu_1}, \dots, a_{\nu_n}],$$

$$(\beta): \langle \eta_1, \dots, \eta_n \rangle, \langle \nu_1, \dots, \nu_n \rangle \text{ are similar in } \kappa \geq \mu.$$

It is easy to check that  $\Phi_\varepsilon = \Phi_{\zeta+1}$  is as required.

So we have defined the sequence  $\langle \Phi_\varepsilon : \varepsilon < \kappa \rangle$  satisfying the requirements above, and let  $\Phi_\kappa$  be its limit. It is as required in the claim. ■2.13

**Claim 2.14.** Assume  $\alpha \leq \kappa$  is a limit ordinal and  $\langle \mathbf{m}_\gamma, \mathbf{h}_\gamma^\beta : \gamma < \beta < \alpha \rangle$  is an inverse system of approximations.

- (1) There are  $\mathbf{m}_\alpha, \mathbf{h}_\gamma^\alpha$  (for  $\gamma < \alpha$ ) such that  $\langle \mathbf{m}_\gamma, \mathbf{h}_\gamma^\beta : \gamma < \beta < \alpha + 1 \rangle$  is an inverse system of approximations continuous at  $\alpha$ .
- (2) For the following properties, if each  $\mathbf{m}_{\gamma+1}$  (for  $\gamma < \alpha$ ) satisfies the property, then so does  $\mathbf{m}_\alpha$ : term closed, semi full, almost full, resplendent, weakly/strongly indiscernible, weakly /strongly nice, **E**- indiscernible for any **E**  $\in \mathbb{E}$ , weakly/strongly good, weakly/strongly excellent.

Proof: Let  $\mathbf{W}_{\mathbf{m}_\alpha} = \bigcup_{\beta < \alpha} \mathbf{W}_{\mathbf{m}_\beta}$ , and let  $M_\beta = M_{\mathbf{m}_\beta}$  for  $\beta < \alpha$ . We shall define

$$\mathcal{F}_\alpha = \mathcal{F}_{\mathbf{m}_\alpha}, M_\alpha = M_{\mathbf{m}_\alpha} \text{ and } N_W^\alpha = N_W^{\mathbf{m}_\alpha} \text{ and } M_b^\alpha = M_b^{\mathbf{m}_\alpha} \text{ below.}$$

First let  $\mathcal{F}_\alpha$  (formal set, consisting of function symbols not of functions),  $h_\beta^\alpha$  ( $\beta < \alpha$ ) be the inverse limit of  $\langle \mathcal{F}_\beta, \mathbf{h}_\gamma^\beta : \gamma \leq \beta < \alpha \rangle$ , i.e.,

$$(\alpha): \mathbf{h}_\beta^\alpha \text{ is a partial function from } \mathcal{F}_\alpha \text{ onto } \mathcal{F}_\beta, \text{ and in Definition 2.12.}$$

$$(\beta): \mathbf{h}_\gamma^\alpha = \mathbf{h}_\gamma^\beta \circ \mathbf{h}_\beta^\alpha \text{ for } \gamma < \beta < \alpha,$$

$$(\gamma): \mathcal{F}_\alpha = \bigcup_{\beta < \alpha} \text{Dom}(h_\beta^\alpha),$$

$$(\delta): \text{ If } \beta_* < \alpha, f_\beta \in \mathcal{F}_\beta, \text{ for } \beta \in [\beta_*, \alpha), \text{ satisfy } \mathbf{h}_\gamma^\beta(f_\beta) = f_\gamma \text{ when } \beta_* \leq \gamma < \beta < \alpha, \text{ then for one and only one } f \in \mathcal{F}_\alpha \text{ we have:}$$

$$\zeta_f = \zeta_{f_\beta} \text{ for } \beta \in [\beta_*, \alpha) \quad \text{and} \quad \eta_{f, \zeta} = \bigcup \{ \eta_{f_\beta, \zeta} : \beta_* \leq \beta < \alpha \},$$

$$(\epsilon): \text{ every } f \in \mathcal{F}_\alpha \text{ has the form of } f \text{ in } (\delta),$$

( $\zeta$ ):  $f_{\rho,\zeta}^*$  are as in (B) of Definition 2.5, i.e., for any  $\rho \in {}^\alpha\mu$  and  $\zeta < \kappa$  we have  
 $\beta < \alpha \Rightarrow \mathbf{h}_\beta^\alpha(f_{\rho \upharpoonright \beta}^*, \zeta) = f_{\rho,\zeta}^{*,\mathbf{m}_\beta}$ .

Second, we similarly choose  $\mathbf{f}_{\mathbf{m}_\alpha}$ .

Thirdly, we choose  $M_\alpha$  and interpretation of  $f$  (for  $f \in \mathcal{F}_\alpha$ ) and  $M_{\bar{b}}^+$  when

$$\bar{b} \in \{\text{Rang}(f) : f \in \mathcal{F}_\alpha \text{ \& } (\forall \zeta < \zeta_f)(\exists \nu \in W)(\eta_\zeta^f \triangleleft \nu)\}$$

for some  $W \in \mathbf{W}_{<\alpha}$ . Though we can use the compactness theorem, it seems to me more transparent to use ultraproduct. So let  $D$  be an ultrafilter on  $\alpha$  containing all co-bounded subsets of  $\alpha$ . Let  $M_\alpha = \prod_{\beta < \alpha} M_\beta / D$ . If  $f \in \mathcal{F}_\alpha$ , let  $\beta_f < \alpha$  and

$\langle f_\gamma : \gamma \in [\beta_f, \alpha) \rangle$  be such that  $\beta_f \leq \gamma < \alpha \Rightarrow \mathbf{h}_\gamma^\alpha(f) = f_\gamma$ , so  $\langle \eta_\zeta^f \upharpoonright \beta_f : \zeta < \zeta_f \rangle$  has no repetitions. Now, when  $\eta_\zeta^f \triangleleft \nu_\zeta \in {}^\kappa\mu$ , let

$$f_{\mathbf{m}}(\dots, \nu_\zeta, \dots) = \langle c_\gamma : \gamma < \alpha \rangle / D,$$

where

$$\begin{aligned} \gamma \in (\beta_f, \alpha) &\Rightarrow c_\gamma = (\mathbf{h}_\gamma^\alpha(f)_{\mathbf{m}_\gamma})(\dots, \nu_\zeta, \dots) \in M_\gamma, \\ \gamma < \beta_f &\Rightarrow c_\gamma \text{ is any member of } M_\gamma. \end{aligned}$$

So  $M_W^\alpha$  is well defined for  $W \in \mathbf{W}_{\mathbf{m}(\alpha)}$ .

Fourth, if  $\bar{b} = \langle b_\varepsilon : \varepsilon < \varepsilon(*) \rangle \in {}^\kappa > (M_W^\alpha)$ ,  $b_\varepsilon = f_\varepsilon^{\mathbf{m}}(\dots, \nu_\zeta, \dots)_{\zeta < \zeta_{f_\varepsilon}}$ , and  $\beta_* < \alpha$  and for  $\gamma \in [\beta_*, \alpha)$ :  $f_{\gamma,\varepsilon} \in \mathcal{F}_{\mathbf{m}_\beta}$ ,  $\langle f_{\gamma,\varepsilon} : \varepsilon < \varepsilon(*) \rangle \in \text{Dom}(\mathbf{f}_{\mathbf{m}_\beta})$ , and  $\mathbf{h}_\gamma^\alpha(f_{\gamma,\varepsilon}) = f_\varepsilon$ , then we let  $\bar{b}^\beta = \langle b_\varepsilon^\beta : \varepsilon < \varepsilon(*) \rangle$  where  $b_\varepsilon^\beta$  is  $f^{\mathbf{m}_\beta}(\dots, \nu_\zeta, \dots)_{\zeta < \zeta_{f_\varepsilon}}$  if  $\beta \in [\beta_*, \alpha)$  and  $b_\varepsilon^\beta$  is any member of  $M_\gamma$  if  $\beta < \beta_*$  and lastly we define  $M_{\bar{b}}^\alpha = \prod_{\beta \in [\beta_*, \alpha)} M_{\bar{b}^\beta}^\beta / D$ .

We still have to check that if for the same  $\bar{b}$  we get two such definitions, then they agree, but this is straightforward.

Fifth, we choose  $M_{\bar{b}}^\alpha$  for other  $\bar{b} \in {}^\kappa > (M_\alpha)$  for which  $M_{\bar{b}}^\alpha$  is not yet defined to satisfy clause (d) of Definition 2.5; note that by the choice of  $\mathbf{W}_{\mathbf{m}_\alpha}$  those choices do not influence the preservation of weakly/strongly indiscernible. So  $\mathbf{m}_\alpha$  is well defined and one can easily check that it is as required. ■2.14

**Claim 2.15.** Assume  $\alpha = \beta + 1 < \kappa$ , and  $\mathbf{m}_1$  is a  $\beta$ -approximation.

- (1) There are  $\mathbf{h}_*$  and an  $\alpha$ -approximation  $\mathbf{m}_2$  such that  $\mathbf{m}_1 \leq_{\mathbf{h}_*} \mathbf{m}_2$ ,  $M_{\mathbf{m}_2} = M_{\mathbf{m}_1}$ ,  $M_{\bar{b}}^{\mathbf{m}_2} = M_{\bar{b}}^{\mathbf{m}_1}$ , and  $\text{Dom}(\mathbf{h}_*) = \mathcal{F}_{\mathbf{m}_2}$ .
- (2) If  $\mathbf{m}_1$  is weakly/strongly nice, then  $\mathbf{m}_2$  is weakly/strongly nice.
- (3) If  $\mathbf{m}_1$  is weakly/strongly indiscernible, then  $\mathbf{m}_2$  is weakly/strongly indiscernible; simply for  $\mathbf{E}$ -indiscernible,  $\mathbf{E} \in \mathbb{E}_\alpha$ .

Proof: (1) Should be clear.

Let  $\alpha(\mathbf{m}_2) = \alpha$ ,  $\mathbf{W}_{\mathbf{m}_2} = \mathbf{W}_{\mathbf{m}_1}$ ,  $M_{\mathbf{m}_2} = M_{\mathbf{m}_1}$  and  $M_{\bar{b}}^{\mathbf{m}_2} = M_{\bar{b}}^{\mathbf{m}_1}$  for  $\bar{b} \in {}^\kappa > (M_{\mathbf{m}_1})$ . Then let

$$\begin{aligned} \mathcal{F}_{\mathbf{m}_2} = \{g_{f,h} : & f \in \mathcal{F}_\beta, h \text{ is a function with domain } \{\eta_{f,\zeta} : \zeta < \zeta_f\} \\ & \text{satisfying } h(\eta_{f,\zeta}) \in \text{Suc}(\eta_{f,\zeta}) = \{\eta_{f,\zeta} \smallfrown \langle \gamma \rangle : \gamma < \mu\}\}, \end{aligned}$$

where for  $g = g_{f,h}$  we let  $\zeta_g = \zeta_f$  and  $\eta_{g,\zeta} = h(\eta_{f,\zeta})$ , and if  $\nu_\zeta \in I_{\eta_{g,\zeta}}$  for  $\zeta < \zeta_g (= \zeta_f)$ , then

$$g_{f,h}^{\mathbf{m}_2}(\dots, \nu_\zeta, \dots) = f^{\mathbf{m}_1}(\dots, \nu_\zeta, \dots) \in M_{\mathbf{m}_1} \prec M_{\mathbf{m}_2}.$$

We define  $\mathbf{h}_*$  by:

$$\text{Dom}(\mathbf{h}_*) = \mathcal{F}_{\mathbf{m}_2} \quad \text{and} \quad \mathbf{h}_*(g_{f,h}) = f.$$

Lastly let

$$\begin{aligned} \text{Dom}(\mathbf{f}_{\mathbf{m}_2}) = \{ \langle g_\varepsilon : \varepsilon < \varepsilon(*) \rangle : & \text{ for some } \bar{f} = \langle f_\varepsilon : \varepsilon < \varepsilon(*) \rangle \in \text{Dom}(\mathbf{f}_{\mathbf{m}_1}) \\ & \text{and a function } h \text{ with domain} \\ & \{ \eta_{f_\varepsilon, \zeta} : \zeta < \zeta_{\bar{f}} \} \text{ i.e., does not depend on } \varepsilon \\ & \text{we have } \varepsilon < \varepsilon(*) \Rightarrow g_\varepsilon = g_{f_\varepsilon, h} \}, \end{aligned}$$

and if  $\mathbf{h}, \bar{f}, \bar{g} = \langle g_{f_\varepsilon, h} : \varepsilon < \zeta_{\bar{f}} \rangle \in \text{Dom}(\mathbf{f}_{\mathbf{m}_2})$  are as above,  $\sigma(\bar{x})$  is a  $\tau[T, \varepsilon(*)]$ -term,  $\bar{x} = \langle x_\xi : \xi \in u \rangle$ , and  $u$  is a finite subset of  $\varepsilon(*)$  and  $(\mathbf{f}_{\mathbf{m}_1}(\bar{f}))(\sigma(\bar{x})) = f$ , then  $(\mathbf{f}_{\mathbf{m}_2}(\bar{g}))(\sigma(\bar{x})) = g_{f,h}$ .

Now check.

2), 3) Easy. ■2.15

**Definition 2.16.** (1) For approximations  $\mathbf{m}_1, \mathbf{m}_2$ , let  $\mathbf{m}_1 \leq^* \mathbf{m}_2$  mean that  $\alpha(\mathbf{m}_1) = \alpha(\mathbf{m}_2)$  and  $\mathbf{m}_1 \leq_{\mathbf{h}} \mathbf{m}_2$  with  $\mathbf{h}$  being the identity on  $\mathcal{F}_{\mathbf{m}_1} \subseteq \mathcal{F}_{\mathbf{m}_2}$ , and  $\mathbf{W}_{\mathbf{m}_1} \subseteq \mathbf{W}_{\mathbf{m}_2}$ , and  $\mathbf{f}_{\mathbf{m}_1} \subseteq \mathbf{f}_{\mathbf{m}_2}$ , the last mean that if  $\bar{f} \in \text{Dom}(\mathbf{f}_{\mathbf{m}_1})$  then  $\bar{f} \in \text{Dom}(\mathbf{f}_{\mathbf{m}_2})$  and the function  $\mathbf{f}_{\mathbf{m}_2}(\bar{f})$  is equal to the function  $\mathbf{f}_{\mathbf{m}_1}(\bar{f})$ .  
 (2) Let  $\mathbf{m}_1 <^* \mathbf{m}_2$  mean that  
 (a):  $\mathbf{m}_1 \leq^* \mathbf{m}_2$ ,  
 (b): if  $\bar{f} \in \mathbb{F}_{\mathbf{m}_1}$  then  $\bar{f} \in \text{Dom}(\mathbf{f}_{\mathbf{m}_2})$ .

**Observation 2.17.** (1)  $\leq^*$  is a partial order,  $\mathbf{m}_1 \leq^* \mathbf{m}_1$ , and

$$\begin{aligned} \mathbf{m}_1 <^* \mathbf{m}_2 &\Rightarrow \mathbf{m}_1 \leq \mathbf{m}_2, \quad \text{and} \\ \mathbf{m}_1 \leq^* \mathbf{m}_2 <^* \mathbf{m}_3 &\Rightarrow \mathbf{m}_1 <^* \mathbf{m}_3, \quad \text{and} \\ \mathbf{m}_1 <^* \mathbf{m}_2 \leq \mathbf{m}_3 &\Rightarrow \mathbf{m}_1 <^* \mathbf{m}_3. \end{aligned}$$

- (2) Each  $\leq^*$ -increasing chain of length  $< \theta^+$  has a lub (essentially its union). If all members of the chain are weakly/strongly indiscernible, then so is the lub.  
 (3) If  $\langle \mathbf{m}_\varepsilon : \varepsilon < \kappa \rangle$  is  $<^*$ -increasing then its lub  $\mathbf{m}$  is resplendent and  $\varepsilon < \kappa \Rightarrow \mathbf{m}_\varepsilon <^* \mathbf{m}$ . So if each  $\mathbf{m}_\varepsilon$  is weakly/strongly good then  $\mathbf{m}$  is weakly/strongly excellent.

PROOF: : Easy.

As a warm up.

**Claim 2.18.** (1) For any  $\alpha$ -approximation  $\mathbf{m}_0$  there is a full, term closed  $\alpha$ -approximation  $\mathbf{m}_1$  such that  $\mathbf{m}_0 \leq^* \mathbf{m}_1$ .  
 (2) If  $\mathbf{m}_0$  is an  $\alpha$ -approximation, then there is a  $\alpha$ -approximation  $\mathbf{m}_1$  such that  $\mathbf{m}_0 <^* \mathbf{m}_1$  and  $\text{Dom}(\mathbf{f}_{\mathbf{m}_1}) = \mathbb{F}_{\mathbf{m}_0}$ .

Proof: 1) Let  $M_{\mathbf{m}_1} = M_{\mathbf{m}_0}$ , and  $M_b^{\mathbf{m}_1} = M_b^{\mathbf{m}_0}$  for  $\bar{b} \in {}^{\kappa} > (M_{\mathbf{m}_0})$ . Let  $\mathbf{W}_{\mathbf{m}_1} = \mathbf{W}_\alpha$ , and let  $\langle \bar{\nu}_\gamma : \gamma < \gamma^* \rangle$  list the sequences  $\bar{\nu} \in {}^{\kappa} > (\kappa\mu)$  such that  $\langle \nu_\zeta \upharpoonright \alpha : \zeta < \text{lg}(\bar{\nu}) \rangle$  is without repetitions and  $\{ \nu_\zeta : \zeta < \text{lg}(\bar{\nu}) \} \notin \mathbf{W}_{\mathbf{m}_0}$ . Let  $\bar{\nu}_\gamma = \langle \nu_{\gamma, \zeta} : \zeta < \zeta_\gamma^* \rangle$  and define  $\bar{\rho}_\gamma = \langle \nu_{\gamma, \zeta} \upharpoonright \alpha : \zeta < \text{lg}(\bar{\nu}_\gamma) \rangle$ , and  $W_\gamma = \{ \nu_{\gamma, \zeta} : \zeta < \zeta_\gamma^* \}$  for  $\gamma < \gamma^*$ . Let  $\beta_\gamma = \text{otp}\{ \gamma_1 < \gamma : (\forall \gamma_2 < \gamma_1)(\bar{\rho}_{\gamma_2} \neq \bar{\rho}_{\gamma_1}) \}$ .

For each  $W \in \mathbf{W}_\alpha \setminus \mathbf{W}_{\mathbf{m}_0}$ , let  $M_W^{\mathbf{m}_1}$  be an elementary submodel of  $M_{\mathbf{m}_1}$  of cardinality  $\theta$  such that

$$\begin{aligned} W_1^* \subseteq W \wedge W_1^* \in \mathbf{W}_{\mathbf{m}_0} &\Rightarrow M_{W_1^*}^{\mathbf{m}_1} \prec M_W^{\mathbf{m}_1} \quad \text{and} \\ \bar{b} \in {}^{\kappa} > (M_W^{\mathbf{m}_1}) &\Rightarrow M_{\bar{b}}^{\mathbf{m}_0} \upharpoonright |M_W^{\mathbf{m}_1}| \prec M_{\bar{b}}^{\mathbf{m}_0}. \end{aligned}$$

Let  $\langle a_{W,i} : i < \theta \rangle$  list the elements of  $M_W^{\mathfrak{m}_1}$ . For  $\beta < \beta_{\gamma^*}$  and  $i < \theta$  we choose  $f_{\beta,i}$  such that if  $\gamma < \gamma^*$  &  $\beta_\gamma = \beta$  then  $\zeta_{f_{\beta,i}} = \lg(\bar{\nu}_\gamma) = \lg(\rho_\gamma) = \lg(\bar{\nu}_{\beta_\gamma})$  and  $\eta(f_{\beta,i}, \zeta) = \rho_{\gamma,\zeta}$ , and we define  $f_{\beta,i}^{\mathfrak{m}_1}$  by: if  $\nu_\zeta \in I_{\rho_{\gamma,\zeta}}$  for  $\zeta < \zeta_{f_{\beta,i}}$ , and  $\langle \nu_\zeta : \zeta < \zeta_{f_{\beta,i}}^* \rangle = \bar{\nu}_\gamma$  then  $f_{\beta,i}^{\mathfrak{m}_1}(\dots, \nu_{\gamma,\zeta}, \dots) = a_{W_{\gamma,i}}$ .

Next,  $\mathcal{F}_{\mathfrak{m}_1}$  almost is  $\mathcal{F}_{\mathfrak{m}_0} \cup \{f_{\beta,i} : \beta < \beta_{\gamma^*}, i < \theta\}$ , just we term-close it. Lastly  $\mathbf{f}_{\mathfrak{m}_1}$  is defined as  $\mathbf{f}_{\mathfrak{m}_0}$  recalling that  $\text{Dom}(\mathbf{f}_{\mathfrak{m}_1})$  is required just to be a subset of  $\mathbb{F}$ .

2) Also easy.

Let  $M^*$  be a  $\|M_{\mathfrak{m}_0}\|^+$ -resplendent elementary extension of  $M_{\mathfrak{m}_0}$ . We define an  $\alpha$ -approximation  $\mathfrak{m}_1$  as follows:

- (a):  $\alpha_{\mathfrak{m}_1} = \alpha_{\mathfrak{m}_0}$ ,  $\mathbf{W}_{\mathfrak{m}_1} = \mathbf{W}_{\mathfrak{m}_0}$ ,  $M_{\mathfrak{m}_1} = M^*$ ,
- (b): if  $\bar{b} \in {}^{\kappa}>(M_{\mathfrak{m}_0})$ , then  $M_{\bar{b}}^{\mathfrak{m}_1}$  is an elementary extension of  $M_{\bar{b}}^{\mathfrak{m}_0}$ ,
- (c):  $\mathbf{f}_{\mathfrak{m}_1} \supseteq \mathbf{f}_{\mathfrak{m}_0}$  and  $\text{Dom}(\mathbf{f}_{\mathfrak{m}_1}) = \mathbb{F}_{\mathfrak{m}_0}$ ,
- (d):  $\mathcal{F}_{\mathfrak{m}_1} = \mathcal{F}_{\mathfrak{m}_0}$
- (e): if  $(\mathbf{f}_{\mathfrak{m}_1}(\bar{f}))(\sigma_\xi(\bar{x}^\xi)) = f$ ,  $\eta(\bar{f}, \zeta) \triangleleft \nu_\eta \in {}^\kappa\mu$ , and

$$\bar{b} = \langle f_\varepsilon^{\mathfrak{m}_1}(\dots, \nu_\zeta, \dots)_{\zeta < \zeta_{\bar{f}}} : \varepsilon < \varepsilon_{\bar{f}} \rangle \quad \text{and} \quad \bar{x}^\xi = \langle x_i^\xi : i \in u \rangle,$$

then

$$f^{\mathfrak{m}_1}(\dots, \nu_\zeta, \dots)_{\zeta < \zeta_{\bar{f}}} = \sigma^{M_{\bar{b}}^{\mathfrak{m}_1}}(\langle f_i(\dots, \nu_\zeta, \dots)_{\zeta < \zeta_{\bar{f}}} : i \in u \rangle).$$

■2.18

**Main Claim 2.19.** *Assume  $\mathfrak{m}_0$  is a weakly nice approximation. Then there is a weakly good approximation  $\mathfrak{m}_1$  such that  $\mathfrak{m}_0 <^* \mathfrak{m}_1$  with  $\mathbf{W}_{\mathfrak{m}_1} = \mathbf{W}_{\mathfrak{m}_0}$ .*

Proof: By 2.18(1)+(2) there is a full term closed  $\mathfrak{m}_1$  such that  $\mathfrak{m}_0 <^* \mathfrak{m}_1$  and  $\text{Dom}(\mathbf{f}_{\mathfrak{m}_1}) = \mathbb{F}_{\mathfrak{m}_0}$ . We would like to “correct”  $\mathfrak{m}_1$  so that it is weakly indiscernible. Let  $\mathfrak{m}_2$  be an  $\alpha_{\mathfrak{m}_1}$ -approximation as guaranteed in the Claim 2.20 below, so it is good and reflecting we clearly see that  $\mathfrak{m}_0 \leq^* \mathfrak{m}_2$  and even  $\mathfrak{m}_0 <^* \mathfrak{m}_2$ .

**Main SubClaim 2.20.** (1) *Assume  $\mathfrak{m}_0$  is a weakly nice  $\alpha$ -approximation and  $\mathfrak{m}_0 <^* \mathfrak{m}_1$  is and  $\text{Dom}(\mathbf{f}_{\mathfrak{m}_1}) = \mathbb{F}_{\mathfrak{m}_0}$  and  $\mathbf{W}_{\mathfrak{m}_1}$  is an ideal (that is closed under finite union). Then there is a good  $\alpha$ -approximation  $\mathfrak{m}_2$  such that:*

- (a):  $\alpha_{\mathfrak{m}_2} = \alpha_{\mathfrak{m}_1}$ ,  $\mathcal{F}_{\mathfrak{m}_2} = \mathcal{F}_{\mathfrak{m}_1}$ ,  $\mathbf{f}_{\mathfrak{m}_2} = \mathbf{f}_{\mathfrak{m}_1}$ , and  $\mathbf{W}_{\mathfrak{m}_2} = \mathbf{W}_{\mathfrak{m}_1}$ .
- (b):  $\mathfrak{m}_0 <^* \mathfrak{m}_2$ ;

(2) *We may add*

(c) *Assume*

- ( $\alpha$ ):  $n < \omega$  and  $f_\ell \in \mathcal{F}_{\mathfrak{m}_1}$ ,  $\nu_\zeta^\ell \in I_{\eta(f_\ell, \zeta)}$  for  $\zeta < \zeta_{f_\ell}$ ,  $\ell < n$ , and  $\Delta$  is a finite set of formulas in  $\mathbb{L}(\tau_T)$
- ( $\beta$ ):  $m < \omega$  and for  $k < m$  we have  $\bar{f}^k = \langle f_\varepsilon^k : \varepsilon < \varepsilon_k \rangle \in \text{Dom}(\mathbf{f}_{\mathfrak{m}_1})$  and  $n_k < \omega$  and  $g_{k,\ell} \in \mathcal{F}_{\mathfrak{m}_2}$  (for  $\ell < n_k$ ) satisfying

$$\langle \eta(g_{k,\ell}, \zeta) : \zeta < \zeta_{g_{k,\ell}} \rangle = \langle \eta(\bar{f}^k, \zeta) : \zeta < \zeta_{\bar{f}^k} \rangle,$$

and  $\nu_{k,\zeta}^\ell \in I_{\eta(\bar{f}^k, \zeta)}$  for  $\ell < n_k, \zeta < \zeta_{\bar{f}^k}$ , and  $\Delta_k$  is a finite set of formulas in  $\mathbb{L}(\tau[\zeta_{\bar{f}}, \tau(T)])$ .

Then we can find  $\rho_\zeta^\ell$  for  $\ell < n_k, \zeta < \zeta_{f_\ell}$  and  $\rho_{k,\zeta}^\ell$  for  $\ell < n_k, \zeta < \zeta_{\bar{f}^k}$  for  $\ell < n_k, k < m$  such that

- (i):  $\rho_\varepsilon^\ell \in I_{\eta(f_\ell, \zeta)}$  for  $\zeta < \zeta_{f_\ell}$  and  $\rho_{k,\zeta} \in I_{\eta(\bar{f}^k, \zeta)}$  for  $\zeta < \zeta_{\bar{f}^k}$  for  $\ell < n, k < m$ ,

- (ii): the sequences  $\langle \rho_\zeta^\ell : \ell < n, \zeta < \zeta_{f_\ell} \rangle \frown \langle \rho_{k,\zeta} : \ell < n_k, k < m, \zeta < \zeta_{\bar{f}^k} \rangle$   
and  $\langle \nu_\zeta^\ell : \ell < n, \zeta < \zeta_{f_\ell} \rangle \frown \langle \nu_{k,\zeta} : \ell < n_k, k < m, \zeta < \zeta_{\bar{f}^k} \rangle$  are similar  
(see Definition ),
- (iii): the  $\Delta$ -type realized by the sequence

$$\langle f_\ell^{\mathbf{m}_2}(\dots, \nu_\zeta^\ell, \dots)_{\zeta < \zeta_{f_\ell}} : \ell < n \rangle$$

in  $M_{\mathbf{m}_2}$  is equal to the  $\Delta$ -type which the sequence

$$\langle f_\ell^{\mathbf{m}_1}(\dots, \rho_\zeta^\ell, \dots)_{\zeta < \zeta_{f_\ell}} : \ell < n \rangle$$

realizes in  $M_{\mathbf{m}_1}$ ,

- (iv): for  $k < m_1$ , the  $\Delta_k$ -type realized by the sequence

$$\langle g_{k,\ell}^{\mathbf{m}_2}(\dots, \nu_{k,\zeta}^\ell, \dots)_{\zeta < \zeta_{\bar{f}^k}} : \ell < n_k \rangle$$

in the model  $M_{\langle f_\epsilon^{k,\mathbf{m}_2} : \epsilon < \epsilon_k \rangle}^{\mathbf{m}_2}(\dots, \nu_{k,\zeta}^\ell, \dots)_{\zeta < \zeta_{\epsilon < \epsilon_k}}$  is equal to the  $\Delta_k$ -type realized by the sequence

$$\langle g_{k,\ell}^{\mathbf{m}_1}(\dots, \rho_{k,\zeta}^\ell, \dots)_{\zeta < \zeta_{\bar{f}^k}} : \ell < n_k \rangle$$

in the model  $M_{\langle f_\epsilon^{k,\mathbf{m}_2} : \epsilon < \epsilon_k \rangle}^{\mathbf{m}_1}(\dots, \nu_{k,\zeta}^\ell, \dots)_{\zeta < \zeta_{\epsilon < \epsilon_k}}$

- (v): if  $k_1, k_2 < m$  then

$$\begin{aligned} \langle f_\epsilon^{k_1, \mathbf{m}_2}(\dots, \nu_\zeta^{k_1}, \dots)_{\zeta < \zeta_{f^{k_1}}} : \epsilon < \epsilon_{k_1} \rangle = \\ \langle f_\epsilon^{k_2, \mathbf{m}_2}(\dots, \nu_\zeta^{k_2}, \dots)_{\zeta < \zeta_{f^{k_2}}} : \epsilon < \epsilon_{k_2} \rangle \end{aligned}$$

if and only if

$$\begin{aligned} \langle f_\epsilon^{k_1, \mathbf{m}_1}(\dots, \rho_\zeta^{k_1}, \dots)_{\zeta < \zeta_{f^{k_1}}} : \epsilon < \epsilon_{k_1} \rangle = \\ \langle f_\epsilon^{k_2, \mathbf{m}_1}(\dots, \rho_\zeta^{k_2}, \dots)_{\zeta < \zeta_{f^{k_2}}} : \epsilon < \epsilon_{k_2} \rangle, \end{aligned}$$

- (vi): if  $\ell < n_k, k < m, \ell^* < n$ , then

$$f_\ell^{\mathbf{m}_2}(\dots, \nu_\zeta^{\ell^*}, \dots)_{\zeta < \zeta_{f_\ell}} = f_{k,\ell}^{\mathbf{m}_2}(\dots, \nu_{k,\zeta}^\ell, \dots)_{\zeta < \zeta_{\bar{f}^k}}$$

if and only if

$$f_\ell^{\mathbf{m}_1}(\dots, \rho_\zeta^{\ell^*}, \dots)_{\zeta < \zeta_{f_\ell}} = f_{k,\ell}^{\mathbf{m}_1}(\dots, \rho_{k,\zeta}^\ell, \dots)_{\zeta < \zeta_{\bar{f}^k}}.$$

**Discussion 2.21.** Now we have to apply the Ramsey theorem to recapture weak indiscernibility. Why we only promise  $\mathbf{m}_0 <^* \mathbf{m}_1$  &  $\text{Dom}(\mathbf{f}_{\mathbf{m}_1}) = \mathbb{F}_{\mathbf{m}_0}$ , not that  $\mathbf{m}_1$  is excellent? As  $T^*[\bar{b}, M]$  is not a continuous function of  $(\bar{b}, M)$  and, more done to earth, as during the proof we need to know the type of  $\bar{b}$  whenever we consider types in  $M_{\bar{b}}^{\mathbf{m}_1}$  in order to know  $T^*[\bar{b}, M_{\mathbf{m}}]$ .

Usually a partition theorem on what we already have is used at this moment, but partition of infinitary functions tend to contradict ZFC. However, in the set  $\Lambda$  expressing what we need, the formulas are finitary. So using compactness we will reduce our problem to the consistency of the set  $\Lambda$  of first order formulas in the variables

$$\{f(\dots, \eta_\zeta, \dots)_{\zeta < \zeta(f)} : f \in \mathcal{F}^{\mathbf{m}_1} \text{ and } \zeta < \zeta_f \Rightarrow \eta(f, \zeta) \triangleleft \eta_\zeta \in {}^\kappa \mu\}.$$

This can be easily reduced to the consistency of a set  $\Lambda$  of formulas in  $\mathbb{L}(\tau_T)$  (first order).

We can get  $\Lambda$  because for all relevant  $\bar{b}$  we know  $T^*[\bar{b}, M]$ .

Proof: Let  $Y = \{y_f(\dots, \nu_\eta, \dots)_{\eta \in w[f]} : f \in \mathcal{F}_{\mathbf{m}_1} \text{ and } \nu_\eta \in I_\eta \text{ for } \eta \in w[f]\}$  be a set of individual variables with no repetitions, recalling that  $w[f] = \{\eta[f, \varepsilon] : \varepsilon < \zeta_f\}$ . For each  $\bar{f} \in \text{Dom}(\mathbf{f}_{\mathbf{m}_1})$  and  $\bar{\nu} = \langle \nu_\eta : \eta \in w[\bar{f}] \rangle$  such that  $\nu_\eta \in I_\eta$ , let  $\tau_{\bar{f}, \bar{\nu}}$  be  $\tau[T, \text{lg} \bar{f}]$  where  $w[\bar{f}] = w[f_\varepsilon]$  for each  $\varepsilon < \text{lg}(\bar{f})$ ; pedantically a copy of it over  $\tau_T$  so  $(f_1, \bar{\nu}_1) \neq (f_2, \bar{\nu}_2) \Rightarrow \tau_{\bar{f}_1, \bar{\nu}_1} \cap \tau_{\bar{f}_2, \bar{\nu}_2} = \tau_T$ . Let  $\tau^* = \bigcup \{\tau_{\bar{f}, \bar{\nu}} : \bar{f}, \bar{\nu} \text{ as above}\} \cup \tau_T$ .

Let  $\mathbf{g}_{\bar{f}, \bar{\nu}}$  be a one to one function from  $\tau[T, \text{lg}(\bar{f})]$  onto  $\tau_{\bar{f}, \bar{\nu}}$  which is the identity on  $\tau_T$  preserve the arity and being a predicate function symbol, individual constant. Let  $\hat{\mathbf{g}}_{\bar{f}, \bar{\nu}}$  be the mapping from  $\mathbb{L}(\tau[T, \text{lg}(\bar{f})])$  onto  $\mathbb{L}(\tau_{\bar{f}, \bar{\nu}})$  which  $\mathbf{g}_{\bar{f}, \bar{\nu}}$  induce.

We now define a set  $\Lambda$  (the explanations are for the use in the proof of  $\boxtimes_1$  below).

$\boxtimes_0 \quad \Lambda = \Lambda_0 \cup \Lambda_1 \cup \Lambda_2 \cup \Lambda_3 \cup \Lambda_4 \cup \Lambda_5 \cup \Lambda_6 \cup \Lambda_7 \cup \Lambda_8$  where

- (a):  $\Lambda_0 = \{\varphi_\zeta(y_{f_{\rho_1, \kappa}}^*(\nu_1), y_{f_{\rho_2, \zeta+1}}^*(\nu_2))^{\mathbf{t}} : \text{where } \mathbf{t} = \text{truth if and only if } [\nu_1 \upharpoonright (\zeta+1) = \nu_2 \upharpoonright (\zeta+1)] \text{ and } \zeta < \kappa, \rho_\ell \in {}^\alpha \mu, \text{ and } \nu_\ell \in I_{\rho_\ell}^\alpha \text{ for } \ell = 1, 2\}$   
[explanation: to satisfy (iii) in clause (B) of Definition 2.5].
- (b):  $\Lambda_1 = \{y_{f_{\rho_1, \zeta}}^*(\nu_1) = y_{f_{\rho_2, \zeta}}^*(\nu_2) : \zeta < \kappa, \rho_\ell \in {}^\alpha \mu, \nu_\ell \in I_{\rho_\ell}^\alpha \text{ for } \ell = 1, 2 \text{ and } \nu_1 \upharpoonright \zeta = \nu_2 \upharpoonright \zeta\}$   
[explanation: to satisfy (ii) in clause (B) of Definition 2.5].
- (c):  $\Lambda_2 = \{y_f(\dots, \nu_\eta, \dots)_{\eta \in w[f]} = \sigma(\dots, y_{f_\ell}(\dots, \nu_\eta, \dots)_{\eta \in w[f]} \dots) : f, \langle f_\ell : \ell < n \rangle \text{ and } \langle \nu_\eta : \eta \in w[f] \rangle \text{ are as in clause (E) of Definition 2.6(4) for } \mathbf{m}_1\}$   
[explanation: this is preservation of the witnesses for closure under terms of  $\tau$ , in clause (E) of Definition 2.6(4) for  $\mathbf{m}_1$ ].
- (d):  $\Lambda_3 = \{y_f(\dots, \nu_\eta, \dots)_{\eta \in w[f]} = \sigma(\dots, f^\ell(\dots, \nu_\eta(f^\ell, \zeta), \dots)_{\zeta < \zeta(f^\ell)}, \dots)_{\ell < n} : f, \langle f^\ell : \ell < n \rangle \text{ and } \langle f_\varepsilon : \varepsilon < \varepsilon(*) \rangle \in \text{Dom}(\mathbf{f}_{\mathbf{m}_0}) \text{ are as in clause (F) of Definition 2.6(4)}\}$   
[explanation: this is preservation of the witness for closure under terms of the  $\tau(M_{\bar{b}})$ -s as in clause (F) of Definition 2.6(4) for  $\mathbf{m}_1$ ].
- (e):  $\Lambda_4 = \{\varphi(\dots, y_{f_\ell}(\dots, \nu_\zeta, \dots)_{\zeta < \zeta^*}, \dots)_{\ell < n} : \varphi(x_0, \dots, x_{n-1}) \in \mathbb{L}(\tau_T) \text{ and } f_\ell \in \mathcal{F}_{\mathbf{m}_0} \text{ and } \zeta^* = \zeta_{f_\ell} \text{ for } \ell < n, \text{ and } \nu_\zeta \in I_{\eta(f_\ell, \zeta)} \text{ for } \zeta < \zeta^* \text{ and } M_{\mathbf{m}_0} \models \varphi[\dots, f_\ell^{\mathbf{m}_0}(\dots, \nu_\zeta, \dots)_{\zeta < \zeta^*}, \dots]_{\ell < n}\}$   
[explanation: this is for being above  $\mathbf{m}_0$ , the  $\mathbb{L}(\tau_T)$ -formulas].
- (f):  $\Lambda_5$  like  $\Lambda_4$  for the  $M_{\bar{b}}$ -s that is  
 $\Lambda_5 = \{\varphi(\dots, y_{f_\ell}(\dots, \nu_\zeta, \dots)_{\zeta < \zeta^*}, \dots)_{\ell < n} : \text{for some } \bar{f}, \bar{\nu} \text{ and } \langle f_\ell : \ell < n \rangle \text{ we have } \varphi(x_0, \dots, x_{n-1}) \in \mathbb{L}(\tau_{\bar{f}, \bar{\nu}}) \text{ and } \bar{f} \in \text{Dom}(\mathbf{f}_{\mathbf{m}_0}), \zeta(\bar{f}) = \zeta^* = \zeta_{f_\ell}, f_\ell \in \mathcal{F}_{\mathbf{m}_0}, \eta(\bar{f}, \zeta) = \eta(f_\ell, \zeta) \text{ for } \zeta < \zeta^*, \ell < n \text{ and } M_{\mathbf{m}_0} \models \varphi[\dots, f_\ell^{\mathbf{m}_0}(\dots, \nu_\zeta, \dots)_{\zeta < \zeta^*}, \dots]_{\ell < n}\}$   
[explanation: this is for being above  $\mathbf{m}_0$ , the formulas from the  $M_{\bar{b}}^{\mathbf{m}_0}$ -s].
- (g):  $\Lambda_6 = \{\varphi(\dots, y_{f_\ell}(\dots, \nu_\zeta^1, \dots)_{\zeta < \zeta^*}, \dots)_{\ell < n} \equiv \varphi(\dots, y_{f_\ell}(\dots, \nu_\zeta^2, \dots)_{\zeta < \zeta^*}, \dots)_{\ell < n} : \varphi(x_0, \dots, x_{n-1}) \in \mathbb{L}(\tau_T) \text{ and } \zeta^* = \zeta(f_\ell), f_\ell \in \mathcal{F}^{\mathbf{m}_1}, \nu_\zeta^k \in I_{\eta(f_\ell, \zeta)} \text{ if } k = 1, 2 \text{ and } \zeta < \zeta^* \text{ such that for exactly one } \zeta < \zeta^* \text{ we have } \nu_\zeta^1 \neq \nu_\zeta^2\}$   
[explanation: this is for weak indiscernibility, see Definition 2.9(1) clause (b) and Definition 2.9(3)].
- (h):  $\Lambda_7 = \{(\forall x_1 \dots x_n)[\varphi_1(x_0, \dots, x_{n-1}) \equiv \varphi_2(x_0, \dots, x_{n-1})] : \text{for some } \bar{f}^1, \bar{f}^2 \in \mathbb{F}_{\mathbf{m}}, \text{lg}(\bar{f}^1) = \text{lg}(\bar{f}^2), \eta(\bar{f}^\ell, \zeta) \triangleleft \nu_\zeta^\ell \in {}^\kappa \mu \text{ for } \zeta < \text{lg}(\bar{f}^\ell) \text{ and } \eta(\bar{f}^1, \zeta_1) = \eta(\bar{f}^2, \zeta_2) \Rightarrow \nu_{\zeta_1}^1 = \nu_{\zeta_2}^2; \bar{\varphi} \in \mathbb{L}(\tau_{\bar{f}^\ell, \bar{\nu}^\ell}) \text{ and } \hat{\mathbf{g}}_{\bar{f}^1, \bar{\nu}^1}^{-1}(\varphi_1) = \hat{\mathbf{g}}_{\bar{f}^2, \bar{\nu}^2}^{-1}(\varphi_2)\}$   
[Explanation: this has to show the existence of the  $M_{\bar{b}}$ : we can avoid this if we change the main definition such that instead  $M_{\bar{b}}$  we have  $M_{\bar{f}, \bar{\nu}}$ ]
- (i):  $\Lambda_8 = \{\varphi(\dots, y_{f_\ell}(\dots, \nu_\zeta^1, \dots)_{\zeta < \zeta^*}, \dots)_{\ell < n} \equiv \varphi(\dots, y_{f_\ell}(\dots, \nu_\zeta^2, \dots)_{\zeta < \zeta^*}, \dots)_{\ell < n} : \text{for some } \bar{f} \in \text{Dom}(\mathbf{f}_{\mathbf{m}_1}), \bar{f}, \bar{\nu}, \bar{\nu}^1, \bar{\nu}^2 \text{ and } \langle f_\ell : \ell < n \rangle \text{ we have } \varphi(x_0, \dots, x_{n-1}) \in$

$\mathbb{L}(\tau_{\bar{f}, \bar{\nu}})$ ,  $f_\ell \in \mathcal{F}_{\mathbf{m}_1}$ ,  $\zeta_{f_\ell} = \zeta^*$ ,  $\eta(f_\ell, \zeta) = \eta_\zeta \in {}^\alpha\mu$  for  $\zeta < \zeta^*$ , and  $w(\bar{f}) \subseteq \{\eta_\zeta : \zeta < \zeta^*\}$ , and for  $k = 1, 2$  we have  $\eta_\zeta \triangleleft \nu_\zeta^k \in {}^\kappa\mu$  for  $\zeta < \zeta^*$ , and  $\eta(\bar{f}, \zeta_1) = \eta_{\zeta_2} \Rightarrow \nu_{\zeta_1} = \nu_{\zeta_2}^k$

Clearly (e.g. for the indiscernibility we use term closure)

( $\boxtimes_1$ ):  $\Lambda$  is a set of first order formulas in the free variables from  $Y$  and the vocabulary  $\tau^*$  such that an  $\alpha$ -approximation  $\mathbf{m}$  satisfying (i) below is as required if and only if clause (ii) below holds where

- (i):  $\mathcal{F}_{\mathbf{m}} = \mathcal{F}_{\mathbf{m}_1}$ ,  $\mathbf{f}_{\mathbf{m}} = \mathbf{f}_{\mathbf{m}_1}$ ,  $\mathbf{W}_{\mathbf{m}} = \mathbf{W}_{\mathbf{m}_1}$ ,
- (ii): interpreting  $y_{f(\dots, \nu_\eta, \dots)}_{\eta \in w[f]} \in Y$  as  $f^{\mathbf{m}}(\dots, \nu_\eta, \dots)_{\eta \in w[f]}$  and the predicates and relation symbols in each  $\tau_{\bar{f}, \bar{\nu}}$  naturally,  $M_{\mathbf{m}}$  is a model of  $\Lambda$  or more exactly not  $M_{\mathbf{m}}$  but the common expansion of the  $M_{\bar{b}}^{\mathbf{m}}$ -s for  $\bar{b} \in \{\langle f_\epsilon^{\mathbf{m}}(\dots, \nu_\zeta, \dots)_{\zeta < \zeta^*} : \epsilon < \epsilon^* \rangle : \bar{f} = \langle f_\epsilon : \epsilon < \epsilon^* \rangle \in \text{Dom}(\mathbf{f}_{\mathbf{m}_0})$ , and  $\nu_\zeta \in I_{\eta(\bar{f}, \zeta)}\}$ .

So it is enough to prove

( $\boxtimes_2$ ):  $\Lambda$  has a model.

We use the compactness theorem, so let  $\Lambda^a \subseteq \Lambda$  be finite. We say that  $\nu \in {}^\kappa\mu$  appears in  $\Lambda^a$ , if for some variable  $y_{f(\dots, \nu_\eta, \dots)}_{\eta \in w[f]}$  appearing as a free variable in some  $\varphi \in \Lambda^a$  we have  $\nu \in \{\nu_\eta : \eta \in w[f]\}$  or some formula in  $\Lambda^a$  belongs to  $\mathbb{L}(\tau_{\bar{f}, \bar{\nu}}) \setminus \mathbb{L}(\tau_T)$ . We may also say “ $\nu$  appears in  $\varphi$ ”, and/or “ $f(\dots, \nu_\eta, \dots)_{\eta \in w[f]}$  appears in  $\Lambda^a$ ” (or in  $\varphi$ ).

Let  $n_0^* = |\Lambda^a|$ . Now, for each  $\eta \in {}^\alpha\mu$  the set of  $\nu \in I_\eta^\alpha$  appearing in  $\Lambda^a$ , which we call  $J_\eta^\alpha$ , is finite but on  $\bigcup_{\eta \in {}^\alpha\mu} J_\eta^\alpha$  we know only that its cardinality is  $< \kappa$ . Note that, moreover,  $n_1^* =: \max\{|J_\eta^\alpha| : \eta \in {}^\alpha\mu\}$  is well defined  $< \aleph_0$  as well as  $m_0^* = |\Lambda^a \cap \Lambda_0|$ . For each  $\eta \in {}^\alpha\mu$  we can find a finite set  $\mathbf{u}_\eta \subseteq \kappa$  such that:

- ( $\otimes$ ): (i): if  $\nu_1 \neq \nu_2 \in J_\eta^\alpha$ , then  $\min\{\zeta : \nu_1(\zeta) \neq \nu_2(\zeta)\} \in \mathbf{u}_\eta$
- (ii): if  $\varphi_\zeta[f_{\rho_1, \kappa}^*(\nu_1), f_{\rho_2, \zeta}^*(\nu_2)]^{\mathbf{t}}$  from clause (B) appears in  $\Lambda^a \cap \Lambda_0$ , then  $\zeta, \zeta + 1 \in \mathbf{u}_\eta$
- (iii):  $\alpha \in \mathbf{u}_\eta$ .
- (iv):  $|\mathbf{u}_\eta| \leq (n_1^*)^2 + 2m_{0+1}^*$ .

Clearly  $n_2^* = \max\{|\mathbf{u}_\eta| : \eta \in {}^\alpha\mu\}$  is well defined ( $< \aleph_0$ ), so without loss of generality,  $\eta \in {}^\alpha\mu \Rightarrow |\mathbf{u}_\eta| = n_2^*$ .

Let  $v \subseteq {}^\alpha\mu$  be finite, in fact of size  $\leq |\Lambda^a| = n_0^*$  such that:

- (I): if  $\varphi_\zeta[y_{f_{\rho_1, \kappa}^*(\nu_1)}, y_{f_{\rho_2, \zeta}^*(\nu_2)}]^{\mathbf{t}}$  appears in  $\Lambda^a \cap \Lambda_0$ , so  $\ell \in \{1, 2\} \rightarrow \nu_\ell \in J_{\rho_\ell}^\alpha$ , then  $\rho_\ell \in v$  for  $\ell \in \{1, 2\}$ ,

Now, for all  $\eta \in {}^\alpha\mu \setminus v$  we replace in  $\Lambda^a$  all members of  $J_\eta^\alpha$  by one  $\nu_\eta \in I_\eta^\alpha$  and we call what we get  $\Lambda^b$ , i.e., we identify some variables. It suffices to prove  $\Lambda^b$  is consistent. Now, by the choice of the set  $v$  also  $\Lambda^b$  is of the right kind, i.e.,  $\subseteq \Lambda$ .

[Why? We should check the formulas  $\varphi$ , in  $\Lambda^a \cap \Lambda_i$  for each  $i \leq 8$ ; let it be replaced by  $\varphi' \in \Lambda^b$ . If in  $\varphi \in \Lambda_0 \cap \Lambda^a$  by clause (ii) of  $\otimes$  this substitution has no affect on  $\varphi$ . If  $\varphi \in \Lambda_1$ , either  $\varphi' = \varphi$  or  $\varphi'$  is trivially true. If  $\varphi \in \Lambda_3$ , clearly  $\varphi' \in \Lambda_3$ . If  $\varphi \in \Lambda_4$  then  $\varphi' \in \Lambda_4$  as  $\mathbf{m}_0$  is nice hence weakly indiscernible, i.e. clause (b) of Definition 2.9(1) (and the demand  $f_\ell \in \mathcal{F}_{\mathbf{m}_0}$ ). If  $\varphi \in \Lambda_5$ , similarly using clause (c) of Definition 2.9(1). Lastly if  $\varphi \in \Lambda_6$  we just note that similarly is preserved and similarly for  $\varphi \in \Lambda_7 \cup \Lambda_8$ ].

We then transform  $\Lambda^b$  to  $\Lambda^c$  by replacing each  $\varphi$  by  $\varphi'$ , gotten by replacing, for each  $\rho \in v$ , every  $\nu \in J_\rho^\alpha$  by  $\nu^{[*]} \in {}^\kappa \mu$  where  $\nu^{[*]}(\beta) = \nu(\beta)$  if  $\beta \in \alpha \cup u_\rho$  and  $\nu^{[*]}(\beta) = 0$  otherwise. It suffices to prove the consistency of  $\Lambda^c$ . Now, the effect is renaming variables and again  $\Lambda^c \subseteq \Lambda$ . Let  $\rho^* = \langle \rho_k^* : k < k^* \rangle$  list the  $\rho \in {}^\kappa \mu$  which appear in  $\Lambda^c$  such that  $\rho \restriction \alpha \in v$ . Let  $\eta_k = \rho_k^* \restriction \alpha$  so  $\eta_k \in v$ , and let  $\Upsilon = \{ \bar{\rho} : \bar{\rho} = \langle \rho_k : k < k^* \rangle, \eta_k \triangleleft \rho_k \in {}^\kappa \mu, (\forall \varepsilon)(\alpha \leq \varepsilon < \kappa \& \varepsilon \notin u_{\eta_k} \rightarrow \rho_k(\varepsilon) = 0) \text{ and } \bar{\rho} \text{ is similar to } \bar{\rho}^* \text{ i.e., for } k_1, k_2 < k^* \text{ and } \varepsilon < \kappa \text{ we have } \rho_{k_1}(\varepsilon) < \rho_{k_2}(\varepsilon) \Rightarrow \rho_{k_1}^*(\varepsilon) < \rho_{k_2}^*(\varepsilon) \}.$

For each  $\bar{\rho} \in \Upsilon$  we can try the following model as a candidate to be a model of  $\Lambda^c$ . It expand  $M_{\mathfrak{m}_1}$ , and if symbols from  $\tau_{\bar{f}, \bar{\nu}} \setminus \tau_T$  appear they are interpreted as their  $\mathbf{g}_{\bar{f}, \bar{\nu}}^{-1}$ -images are interpreted in  $M_{\langle f_\varepsilon(\bar{\nu}) : \varepsilon < \text{lg}(\bar{f}) \rangle}^{\mathfrak{m}_1}$ . Lastly we assign to the variable  $y_f(\dots, \nu_\zeta, \dots)_{\zeta < \zeta_f}$  appearing in  $\Lambda^c$  the element  $f_{\mathfrak{m}_1}(\dots, \nu_\zeta, \dots)_{\zeta < \zeta_f}$  of  $M_{\mathfrak{m}_1}$ . Call this the  $\bar{\rho}$ -interpretation. Considering the formulas in  $\Lambda^c \cap \Lambda_i$  for  $i \in \{0, \dots, 5, 7\}$  they always holds. For the formulas in  $\Lambda^c \cap \Lambda_6, \Lambda_8$  we can use a partition theorem on trees with  $|n_2^*| < \aleph_0$  levels (use [Sh:E59, 1.16](4), which is an overkill, but has the same spirit (or [Sh:c, AP2.6, p.662])). ■2.20

**Claim 2.22.** *There is an increasing continuous inverse system of approximations*

$$\langle \mathfrak{m}_\gamma, \mathbf{h}_\beta^\alpha : \gamma \leq \kappa, \beta \leq \alpha \leq \kappa \rangle$$

such that each  $\mathfrak{m}_\gamma$  is weakly excellent.

Proof: By induction on  $\alpha \leq \kappa$  we choose  $\mathfrak{m}_\alpha$  and  $\langle \mathbf{h}_\beta^\alpha : \beta < \alpha \rangle$  with our inductive hypothesis being

(\*) item[(a)]  $\langle \mathfrak{m}_{\beta_1}, \mathbf{h}_\gamma^\beta : \beta_1 \leq \alpha, \gamma < \beta \leq \alpha \rangle$  is an inverse system of approximations,

$\mathfrak{m}_\beta$  is a weakly excellent  $\beta$ -approximation, there is

For  $\alpha = 0$ :

A weakly excellent good 0-approximation exists by 2.13.

For  $\alpha$  limit:

Clearly  $\langle \mathfrak{m}_{\beta_1}, \mathbf{h}_\gamma^\beta : \beta_1 < \alpha, \gamma < \beta < \alpha \rangle$  is an inverse system of good weakly excellent approximations with  $\alpha(\mathfrak{m}_\beta) = \beta$ . So by 2.14 we can find  $\mathfrak{m}_\alpha, \mathbf{h}_\beta^\alpha$  ( $\beta < \alpha$ ) as required.

For  $\alpha = \beta + 1$ :

By 2.15(1+2) there is  $\mathfrak{m}_{\alpha,0}^*$  a weakly nice  $\alpha$ -approximation such that  $\mathfrak{m}_\beta \leq^* \mathfrak{m}_{\alpha,0}^*$ . By 2.19 there is a full term closed  $\alpha$ -approximation  $\mathfrak{m}_{\alpha,1}^*$  such that  $\mathfrak{m}_{\alpha,0}^* \leq^* \mathfrak{m}_{\alpha,1}^*$  and  $\mathfrak{m}_{\alpha,1}^*$  is good. We can choose by induction on  $\epsilon \in [1, \kappa]$  good  $\alpha$ -approximations  $\mathfrak{m}_{\alpha,\epsilon}, \leq^*$ -increasing continuously,  $\mathfrak{m}_{\alpha,\epsilon} <^* \mathfrak{m}_{\alpha,\epsilon+1}$ .

For  $\epsilon = 1$ ,  $\mathfrak{m}_{\alpha,\epsilon}$  is defined; for  $\epsilon$  limit use 2.17(2), for  $\epsilon$  successor use 2.19, and  $\mathfrak{m}_\alpha =: \mathfrak{m}_{\alpha,\kappa}$  is good by 2.17(3). ■2.22

**Claim 2.23.** *Assume  $\mathfrak{m}_\alpha, \mathbf{h}_\gamma^\alpha$  for  $\alpha \leq \kappa, \gamma < \alpha$  as in 2.22 with  $\mu = \lambda$  and  $\lambda = \lambda^\kappa \geq \theta$  (e.g.,  $\lambda = \lambda^\kappa \geq 2^{|T|}$ ). Then there are  $> \lambda$  pairwise non-isomorphic  $\kappa$ -resplendent models of  $T$  of cardinality  $\lambda$ .*

Proof: Let  $\mathfrak{m} = \mathfrak{m}_\kappa$  and  $I \subseteq {}^\kappa \lambda, |I| = \lambda$  and for simplicity  $\{\eta \in {}^\kappa \lambda : \eta(\varepsilon) = 0 \text{ for every large enough } \varepsilon < \kappa\} \cup {}^\kappa > \lambda \subseteq I$ . Let  $M_I$  be the submodel of  $M_{\mathfrak{m}}$  with universe

$$\left\{ f(\dots, \nu_{\eta(f,\zeta)}, \dots)_{\zeta < \zeta_f} : f \in \mathcal{F}_{\mathfrak{m}} \text{ and } \eta(f, \zeta) \in I \cap {}^\kappa \lambda \text{ for every } \zeta < \zeta_f \right\}.$$



Trivially,  $\|M_I\| \leq \lambda^\kappa = \lambda$  and by clause (B) of Definition 2.5 clearly by 2.1(1) it follows that the sequence  $\langle a_\eta : \eta \in {}^\varepsilon \lambda \rangle$  is with no repetitions for each  $\varepsilon < \lambda$  hence by the indiscernibility the sequence  $\langle a_\eta : \eta \in I \rangle$  is with no repetition, so  $\|M_I\| \geq |I| \geq \lambda$ , so  $\|M_I\| = \lambda$ .

Now,  $M_I$  is a  $\kappa$ -resplendent model of  $T$  as  $\mathfrak{m}$  being weakly excellent is full and resplendent.

For  $\zeta < \kappa$ ,  $\nu \in {}^\zeta \lambda$  let  $a_\nu = f_{\eta, \zeta}^{*, \mathfrak{m}_\kappa}(\eta) (\in M_I)$  for any  $\eta \in I_\nu^\zeta \cap I$ .

The point is:

**(b)⊗:** For  $\eta \in {}^\kappa \lambda$ ,  $\nu_\gamma \in {}^{\gamma+1} \lambda$ ,  $\nu_\gamma \restriction \gamma = \eta \restriction \gamma$ ,  $\nu_\gamma \neq \eta \restriction (\gamma+1)$ , we have:

⊗ the type  $\{\varphi(x, a_{\eta \restriction (\gamma+1)}) \equiv \neg \varphi(x, a_{\nu_\gamma}) : \gamma < \kappa\}$   
is realized in  $M_I$  if and only if  $\eta \in I$ .

[Why? The implication “ $\Leftarrow$ ” holds by clause (B)(iii) of Definition 2.5. For the other direction, if  $c \in M_I$ , then for some  $W \in \mathbf{W}_\kappa$ , satisfying  $W \subseteq I$ , we have  $c \in N_W^{\mathfrak{m}}$ , and as  $\eta \notin I$  and  $|W| < \kappa$  clearly for some  $\alpha < \kappa$  we have

$$\{\nu : \eta \restriction \alpha \triangleleft \nu \in {}^\kappa \mu\} \cap W = \emptyset.$$

Let  $c = f_{\mathfrak{m}_\kappa}(\dots, \nu_\zeta, \dots)_{\zeta < \zeta_f}$ , where  $f \in \mathcal{F}_\kappa$ , so  $\nu_\zeta = \eta(f, \zeta)$ . By the continuity of the system, for some  $\gamma \in (\alpha, \kappa)$  we have  $f \in \text{Dom}(\mathbf{h}_\gamma^\kappa)$ , and it suffices to prove that

$$M_I \models “\varphi[c, a_{\eta \restriction (\gamma+1)}] \equiv \varphi[c, a_{\nu_\gamma}]”.$$

By the definition of a system,  $\mathfrak{m}$  is full. Choose  $\nu \in I_{\nu_\zeta}$ ; recalling  $\mathfrak{m}_\gamma \leq_{\mathbf{h}_\gamma^\kappa} \mathfrak{m}_\kappa$  it suffices to prove that

$$M_{\mathfrak{m}_\gamma} \models “\varphi[(\mathbf{h}_\gamma^\kappa(f))(\dots, \nu_\zeta, \dots)_{\zeta < \zeta_f}, f_{\eta \restriction \gamma, \gamma}^*(a_\eta)] \equiv \varphi[(\mathbf{h}_\gamma^\kappa(f))(\dots, \nu_\zeta, \dots)_{\zeta < \zeta_f}, f_{\nu \restriction \gamma, \gamma}^*(a_\nu)]”.$$

But  $\mathfrak{m}_\gamma$  is weakly excellent, hence it is  $\mathbf{E}_\gamma^0$ -indiscernible, and hence the requirement holds. ]

Now use [Sh:309, §2] to get among those models,  $> \lambda$  non-isomorphic; putting in the eventually zero  $\eta \in {}^\kappa \lambda$  does not matter.

■1.9

■2.23

## 3. STRENGTHENING

**Claim 3.1.** *If there is strongly excellent  $\kappa$ -approximation  $\mathfrak{m}$  and  $\mu \geq \lambda = \lambda^\kappa \geq 2^{|T|}$ , then  $T$  has  $2^\kappa$  non-isomorphic  $\kappa$ -resplendent models of cardinality  $\lambda$ .*

Proof: This time use Theorem [Sh:331, 2.3]. For any  $I \subseteq {}^\kappa \geq \lambda$  which includes  ${}^\kappa > \lambda$ , let  $M_I \prec M_{\mathfrak{m}_\kappa}$  be defined as in the proof of 2.23. For  $\eta \in {}^\kappa \lambda$  let  $a_\eta = f_{\eta, \kappa}^*(\eta)$ , and for  $\eta \in {}^\kappa > \lambda$  of length  $\gamma + 1$  let  $\eta' = \eta \upharpoonright \gamma \cap \langle \eta(\gamma) + 1 \rangle$ , and for any  $\nu \in I_\eta$ ,  $\nu' \in I_{\eta'}$  let  $\bar{a}_\eta = \langle f_{\nu, \gamma+1}^*(\nu), f_{\nu', \gamma+1}^*(\nu') \rangle$ ; the choice of  $(\nu, \nu')$  is immaterial. Let

$$\varphi(\langle \bar{x}_\alpha : \alpha < \kappa \rangle) = (\exists y) \left( \bigwedge_{\alpha < \kappa} (\varphi(y, x_{\alpha,0}) \equiv \neg \varphi(y, x_{\alpha,1})) \right).$$

Now we can choose  $f_I : M_I \rightarrow \mathcal{M}_{\lambda, \kappa}$  such that

- (a): if  $f_I(b) = \sigma(\langle t_i : i < i^* \rangle)$  such that  $t_i \in I \cap {}^\kappa \lambda$  with no repetitions and  $\sigma \in \tau[\mathcal{M}_{\lambda, \tau}]$ ,  
then for some  $W \in \mathbf{W}_\mathfrak{m}$  and  $\gamma < \kappa$  such that  $\langle \eta \upharpoonright \gamma : \eta \in W \rangle$  is with no repetition we have  $\{t_i : i < i^*\} = W$  and for some  $f \in \mathcal{F}_\mathfrak{m}$  with  $\zeta_f = \zeta_*$ , and  $\eta(f, \zeta) = t_\zeta$  for  $\zeta < \zeta^f$  we have  $b = f_\mathfrak{m}(\dots, t_\zeta, \dots)_{\zeta < \zeta_f}$  and
- (b):  $f_I(b) = \eta \in I$  if  $b = a_\eta$  (see above).

The new point is that we have to prove the statement  $(*)$  in [Sh:331, 2.3](c)( $\beta$ ).

So assume that for  $\ell = 1, 2$  and  $\alpha < \kappa$ :  $\bar{b}_\alpha^\ell \in {}^2(M_{I_\ell})$ ,  $f_{I_\ell}(\bar{b}_\alpha^\ell) = \bar{\sigma}_\alpha^\ell(\bar{t}_\alpha^\ell)$ , and  $\bar{t}_\alpha^1 = \langle t_{\alpha, \varepsilon}^2 : \varepsilon < \varepsilon_\alpha \rangle$ . Assume furthermore that  $\bar{\sigma}_\alpha^1 = \bar{\sigma}_\alpha^2$ ,  $\bar{t}_\alpha^1 = \bar{t}_\alpha^2$  for  $\alpha < \kappa$  (call it then  $\bar{\sigma}^\alpha(\bar{t}_\alpha)$  though possibly  $I_1 \neq I_2$ ), and the truth value of each statement

$$(\exists \nu \in I_\ell \cap {}^\kappa \lambda) \left( \bigwedge_{i < \kappa} \nu \upharpoonright \varepsilon_i = t_{\beta_i, \gamma_i}^\ell \upharpoonright \varepsilon_i \right)$$

does not depend on  $\ell \in \{1, 2\}$ . Assume further that  $M_{I_1} \models \varphi(\dots, \bar{b}_\gamma^1, \dots)_{\gamma < \kappa}$ , and we shall prove that  $M_{I_2} \models \varphi(\dots, \bar{b}_\gamma^2, \dots)_{\gamma < \kappa}$ ; this suffices.

First note that, as  $f_{I_1}, f_{I_2} \subseteq f_{(\kappa \geq \lambda)}$ , necessarily  $\bar{b}_\alpha^1 = \bar{b}_\alpha^2$  (so call it  $\bar{b}_\alpha$ ). Now,  $M_{I_1} \models \varphi(\dots, \bar{b}_\gamma^1, \dots)_{\gamma < \kappa}$  means that for some  $c_1 \in M_{I_1}$  we have

$$M_{I_1} \models \bigwedge_{\gamma < \kappa} \varphi[c_1, b_{\gamma,0}] \equiv \neg \varphi[c_1, b_{\gamma,1}],$$

and let  $c_1 = f_1(\dots, \eta, \dots)_{\eta \in w[f_1]}$ . Let

$$\begin{aligned} J &= \{ \eta : \eta \trianglelefteq t_{\alpha, j} \text{ for some } \alpha < \kappa, j < \text{lg}(\bar{t}_\alpha) \} \quad \text{and} \\ J_\ell^+ &= \{ \eta : \eta \in I_\ell \text{ or } \text{lg}(\eta) = \kappa \text{ and } (\forall \alpha < \kappa)(\eta \upharpoonright \alpha \in J) \}. \end{aligned}$$

By the assumption,  $J$  is  $\triangleleft$ -closed,  $J \subseteq I_1 \cap I_2$ , moreover  $J_1^+ = J_2^+$ . Let  $\gamma < \kappa$  be minimal such that  $\eta \in w[f_1] \setminus J^+ \Rightarrow \eta \upharpoonright \gamma \notin J$ , and the sequence  $\langle \eta(f_1, \zeta) \upharpoonright \gamma : \zeta < \zeta_f \rangle$  is with no repetitions and  $f_1 \in \text{Dom}(\mathbf{h}_\gamma^\kappa)$ .

Now we can choose  $\nu_\varepsilon \in I_{\eta(f_1, \zeta) \upharpoonright \gamma}$  from  $I_2$  such that  $\eta(f_1, \zeta) \in J^+ \Rightarrow \nu_\varepsilon = \eta(f_1, \zeta)$ . Let  $f_2 \in \mathcal{F}_{\mathfrak{m}_\kappa}$  be such that  $h_\gamma^\kappa(f_2) = h_\gamma^\kappa(f_1)$  and  $\eta(f_2, \zeta) = \nu_\zeta$  for  $\zeta < \zeta_{f_2} = \zeta_{f_1}$ . Easily,  $c_2 = f_\mathfrak{m}^\kappa(\dots, \nu_\zeta, \dots)_{\zeta < \zeta_{f_1}} \in M_{I_2}$  witness that

$$M_{I_2} \models (\exists y) \left[ \bigwedge_{\alpha < \kappa} \varphi_\alpha(x, b_{\alpha,0}) \equiv \neg \varphi(x, b_{\alpha,1}) \right]$$

(recalling  $M_{I_1}, M_{I_2} \prec M_{(\kappa \geq \lambda)}$ ).

Recall and add

■3.1

- Definition 3.2.** (1)  $\mathbf{E}_\alpha^1 \in \mathbb{E}$  (see Definition 2.8) is defined like  $\mathbf{E}_\alpha^0$  (see Definition 2.8(3)) except that we omit clause (iv) there.
- (2) For  $\alpha < \kappa$  define  $\mathbf{E}_\alpha^2 \in \mathbb{E}$  as the following equivalence relation on  $\{\bar{\nu} : \bar{\nu} \in {}^{\kappa >}(\kappa\mu), \bar{\nu} \text{ with no repetition}\}$
- $\bar{\nu}^1 \mathbf{E}_\alpha^2 \bar{\nu}^2$  if and only if
- (i)  $\bar{\nu}^1, \bar{\nu}^2 \in {}^{\kappa >}(\kappa\mu)$  are with no repetition.
  - (ii)  $\bar{\nu}^1, \bar{\nu}^2$  have the same length, all it  $\zeta^*$ .
  - (iii)  $\nu_\zeta^1 \upharpoonright \alpha = \nu_\zeta^2 \upharpoonright \alpha$  for  $\zeta < \zeta^*$ .
  - (iv) for every  $\zeta \in {}^\alpha\mu$ , the sets  $u_\eta^\ell = \{\zeta < \zeta^* : \eta \triangleleft \nu_\zeta^\ell\}$  are finite equal and  $\langle \nu_\zeta^1 : \zeta \in u_\eta^1 \rangle, \langle \nu_\zeta^2 : \zeta \in u_\eta^2 \rangle$  are similar.

- Claim 3.3.** (1) In 2.22 we can demand that every  $\mathfrak{m}_\gamma$  is  $\mathbf{E}_\gamma^1$ -indiscernible i.e. get the strong version.
- (2) Moreover we can get even  $\mathbf{E}_\alpha^2$ -indiscernibility.

Proof:

(1) Very similar to the proof of 2.22. In fact, we need to repeat §2 with minor changes. One point is that defining “good” we use  $\mathbf{E}_\gamma^1$ ; the second is that we should not that this indiscernibility demand is preserved in limits, this is 2.14, 2.17. In fact this is the “strongly” version which is carried in §2 the until 2.19. From then on we should replace “weakly” by “strongly” and change the definition of  $\Lambda_6, \Lambda_8$  appropriately in the proof of 2.20.

(2) Similarly, only we need a stronger partition theorem in the end of the proof of 2.20, but it is there anyhow. ■3.2

**Remark 3.4.** Clearly in many cases in 3.1,  $\lambda = \lambda^{<\kappa} \geq \theta$  suffices, and it seems to me that with high probability for all. Similarly for getting many  $\kappa$ -resplendent models no one elementarily embeddable into another.

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